Construction Project Management

Planning, Scheduling and Controlling

Third Edition

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To

The Martyrs who sacrificed their lives to free the Indian subcontinent from the colonial rule

Let us resolve to perform with devotion and to strive towards excellence in all spheres of individual and collective activity, so that the nation constantly rises to higher levels of endeavour and achievement

Preface to the Third Edition

1. Salient Features

This book, as mentioned in the ealier editions, is on the practical application of the knowledge and skills required in Project Planning, Scheduling and Controlling Techniques in the construction project scope, time, resources, cost, risk and integration. The fast growing construction industry, demands regular updating of the knowledge areas and skills in project management. This updating of project management techniques is the main focus of this edition.

In this Third Edition, within the limited scope and size of the book, the notable additions are as under:

1. Project Manager's competency skills and project success strategy.
2. Basic theory of probability distributions, probabilistic decision networks and decision trees.
3. Introduction to project management software including Enterprise Project Management, Monte Carlo simulation applications using Crystal Ball Software and risk quantification techniques using Project Risk Analysis software.
4. Excel 2007-Solver software applications in solving problems related to resources allocation.
5. Application of cloud computing in data processing.
6. Construction Contract Accounting Standard, and construction workers safety guidelines .
7. An overview of construction contract administration and disputed claims management.
8. Project internal performance audit guidelines.

The structure of the Third Edition differs from the previous editions. Keeping in view the varying requirements of the readers, new topics and new appendices (fifteen to be precise) have been added in this Edition, and are placed at the end of each chapter. Titles of the chapters are similar to the previous edition and the text is divided under the following heads:

- Introducing Construction Project Management. It includes Chapters 1 and 2 which deal with 'Construction Projects Management Framework' and 'Project Scope and Integration Planning'. They also provide an overview of the subjects covered in the book. Appendices include Project Manager's competency skills and project success strategy development.

- Developing Project Construction Time Schedule. It consists of Chapters 3 to 6, on planning and scheduling of project construction time. It includes the processes of defining project activities, sequencing activities using network analysis techniques and scheduling project work. Appendices include project time-cost function, probabilistic decision networks and project management software applications.
- Developing Project Resources Plans. It includes Chapters 7 to 10. These are devoted to planning and forecasting requirements of construction manpower, materials and equipment. Appendices highlight workers incentive schemes, resources allocation using linear programming problems, equipment output norms, and time value of money.
- Planning and Budgeting Construction Costs. Chapters 11 and 12 cover methodology for planning and budgeting costs in construction projects. The relevant Appendices include breakeven analysis and capital investment analysis techniques.
- Controlling Project Construction Plan. Chapters 13 to 18 deal with monitoring and controlling of project integration, scope, product quality, resources, costs, earned value, time schedule, management of risk costs, performance audit guidelines and project management information system. The Appendices include: construction contract administration and claim management, construction contract accounting standard, construction workers safety checklist, probability distributions and Monte Carlo simulation using Crystal Ball software, introduction to Oracle risk management software, and application of cloud computing.

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contribution in developing soft copy of this edition. His suggestions with regard to rearranging the topics especially those related to worker safety are invaluable. The author appreciates his valuable contribution and untiring efforts in manuscript compilation of this book.

This Third Edition of the book would not have been possible without the professional and academic experiences gained from a number of organisations, both in India and abroad, in which the author had the privilege to serve and participate. In gratitude, I salute my past and present superiors, colleagues and subordinates for their direct and indirect contribution in developing this book.

I thank Mr. Kaushik Bellani, M.D., the executives, sponsoring editor, production manager, marketing manager and the staff of McGraw-Hill Education, India, and their copyeditors for their untiring efforts in bringing this book in its present form.

Despite the best efforts, the author, supporters and contributors including Oracle/ Primavera Systems, and ENR of USA; accept no responsibility for any inaccuracy, errors or omissions in the contents of this book.

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Preface to the First Edition

Construction Project Management, in its present form, is the end product of my over 25 years experience at senior level of planning and managing major construction projects, both in India and the Middle East; and imparting instructions on the subject to practicing professionals, engineers and engineering students.

Project is a mission, undertaken to create a unique facility, product or service within the specified scope, quality, time, and costs. With the emerging global opportunities, projects cross geographical boundaries, corporate channels, traditional systems and cultural diversities. The knowledge areas needed to manage such projects comprise project management techniques, general management practices and technology-related subjects. The project management techniques of planning, scheduling and controlling are the tools and devices that bind the subject's knowledge areas. These techniques can be applied to all types of projects. This book covers their application in the field of construction.

The construction industry accounts for 6–9% of the Gross Domestic Product (GDP) of many countries. The value of annual construction activity in the world exceeds one trillion dollars. Unfortunately, due to the secretive nature of construction business, knowledge gained in planning, scheduling and controlling construction process is rarely disseminated. Consequently, the cost of inefficiency is being incurred as a recurring cost. Moreover, in various businesses, the rate of business failure of construction contractors is one of the highest. One of the reasons for this high rate of failures is the lack of knowledge.

There is a vast scope for improving performance through knowledge in the construction industry, where men, materials, machinery, money and management work together to build a facility. Perhaps, it is one of the rare industries in the world that can provide such a vast scope for cost and time reduction at micro-level.

This book describes the planning, scheduling and controlling of time and cost in construction projects. Though vital for performance improvement, this subject is often neglected. The subject covered in this book is divided into four parts spanning eighteen chapters and the text is illustrated with real life cases:

- **Construction Project Management Overview**   Chapters 1 and 2 provide an introduction to the subject. They cover the nature of construction industry, describe construction project concepts and characteristics, and outline project development process.

While highlighting salient features of the project management process, they explain the causes for project failures, outline approach and importance of planning, scheduling and controlling in construction projects, including the functions and role of the chief planner.

- **Time Planning**   Chapter 3 describes the methodology for breaking down project work into activities and for activity duration estimation. Chapters 4 and 5 cover the methodology for modelling and time analysis of CPM, PERT and Precedence networks.

Preparation of time-limited and resources-limited schedules are described in Chapter 6.

- **Resource Planning**   This part containing six chapters is devoted to the strategy for planning manpower, construction materials, plant and machinery, production costs and project budget.
- **Planning Control System**   This part containing six chapters deals with organization of control system; techniques for controlling resource productivity, costs and time; codification of planning system; and management of project information system using computers.

Each chapter of Construction Project Management can be expanded into a volume, but its scope has been restricted to the present size by making trade-offs between technique elaboration and their application coverage. A comprehensive bibliography has been included to supplement information on each topic. A CD-ROM covering lesson plans and self-test exercises for on-line study of the subject covered in the book is being prepared, and is likely to be available by the end of 1999

This book is designed for use by:

- Project managers and their team members
- Managers in corporate office dealing with the managment and execution of construction projects
- Academician, trainers and trainees connected with project management
- Consultants and specialists like architects, engineers, quantity-surveyors, accountants and other managers associated with projects
- Practicing engineers and students studying construction management and those new to the concept and techniques used in Project Management

The subjects covered mainly deal with contractor-oriented Project Management, as well as client-directed Project Management. This book presupposes fundamental engineering knowledge and familiarity with construction process and practices.

My interest in project management knowledge areas started in the early seventies, when as Commander Works Engineer of a Cantonment Construction Project, I conducted a number of project management courses to train the staff and engineer officers of the Military Engineering Services in India. Since then, I have been teaching and practising management of construction projects.

Despite best efforts, the possibility of some errors in the book cannot be ruled out. I welcome readers' comments to make improvements in this book. My e-mail addresses are chitkara@ icpm.com, chitkara@nda.vsnl.net.in

It is hoped that the subject covered in this book will stimulate wider discussions and, enable further development of project management techniques.

Acknowledgements

This book would not have been possible without the construction and academic experiences gained from the many organizations, both in India and the Middle East, where I had the privilege to serve. In gratitude, I salute my superiors, colleagues and subordinates for their direct and indirect contribution in developing this book. I am thankful to my friends who read the manuscript and made useful suggestions.

In particular, I am grateful to the following:

- Lt Gen. S N Sharma, PVSM, AVSM, retired Engineer-in-Chief of the Indian Army, for launching me into the field of project management.
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Last but not the least, I am thankful to my family for their understanding and continuing support which saw me through the extended working hours.

K K Chitkara

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Construction Projects Management Framework

Construction activity has been in existence since the caveman started building his dwelling. Construction has created many wonders in the world and has provided many facilities for the benefit of the mankind. Construction is a major component of the new investments. The construction industry is essential for the growth of the economy of any country. Universally, the construction of capital intensive facilities is undertaken by 'projectising' them, i.e. organising the major works into one or more construction projects for implementation.

Construction projects contain numerous interdependent and interrelated activities. These projects employ voluminous resources. The fast changing environment of the present era imposes numerous time, cost, finance, legal, ethical, environmental and logistic constraints, and include difficulties, uncertainties and risks. Although the concept of projectising construction is not new, project management is a young and emerging discipline. The studies reveal that most of the construction projects face time and cost overruns mostly due to management failures.

This chapter provides an overview of the construction industry; and features the processes, environments and organisation of the construction project management. The chapter is divided into the following sections:

1. Construction Landmarks
2. Construction Scope
3. Project Concept and Features
4. Construction Project Characteristics
5. Construction Project Development: Phases and Processes
6. Construction Project Management Practice
7. Construction Project Management Organisation
8. Role and Functions of Construction Project Manager
9. Main Causes of Project Failure
10. Importance of Integrated Planning, Scheduling and Controlling of Construction Projects

Construction Project Manager's Competency Skills are highlighted in **Appendix A**. Strategy for Project's Success development is covered in **Appendix B**.

❑ 1.1 CONSTRUCTION LANDMARKS

1.1.1 World Famous Constructions

Ever since the dawn of civilisation, man has been involved in some form of construction activity. Even in ancient times, man created architectural marvels, which came to be regarded as the wonders of the world. These include the Pyramids of Egypt, the Great Wall of China, the Angkor temples of Cambodia, and the Tower of Babel. The pyramid of Giza in Egypt contains more than 2 000 000 blocks, with an average weight of about 2.3 tons each. About 100 000 persons worked on the pyramids for three to four months a year to build it in about 20 years. The Great Wall of China, built to provide protection against surprise enemy raids, is about 6400 km long and its height and width at the top varies from 5 to 10 m. It has 20 m high towers placed every few hundred metres. The medieval times witnessed the construction of marvels like Taj Mahal in India and the Leaning Tower of Pisa in Italy. The religious monuments and tombs reveal the superb workmanship of the construction process of the medieval ages. A more recent example of man's achievement in this direction is the Burj Khalifa, one of the world's tallest buildings which is in Dubai, UAE. The world-famous landmarks, constructed in the recent past are listed in **Table l.1**.

1.1.2 World's Largest Projects and Programmes

In the present day world, technological breakthroughs have revolutionised construction activity. Modern construction areas include high-rise buildings, dams and irrigation networks, energy conversion and industrial plants, environmental protection works, infrastructural facilities like roads, bridges, railways, airports and seaports, satellite launching stations, onshore and offshore oil terminals, etc. A glimpse of some of the famous construction-related international programmes, valuing US$ 5 billion and above, as mentioned in ENR Facts, 2003, are listed in **Table 1.2**.

1.1.3 High-Tech Construction Technology

The do-it-yourself construction activity started when the caveman learnt to build his dwelling using stone and his back. The performance enhanced gradually with the slow pace of evolution of technology of levers, wedges, derricks, wheels, rollers and pulleys. The industrial revolution of 1800s enabled the builders to use steam-operated tools and machinery like cranes, hoists, dozers, excavators and shovels to partly replace the human muscles and the load carrying animals. In the twentieth century, the electrical technology and the internal combustion engines replaced the steam with more efficient devices. This resulted in the emergence of high-tech plants and mobile machinery. The capacity of some of the modern mobile construction machines is given in **Table 1.3**.

Construction technology and new materials are emerging at an accelerated pace. Traditionally, in the developing countries, concrete slab construction in multi-storied buildings takes a fortnight

Table 1.1

World-Famous Construction Landmarks

Facility	Name	Location	Cost	Features	Completed
BUILDINGS					
World's Tallest	Burj Khalifa	Dubai, UAE	NA	828 metres tall	2010
World's Largest by Floor Area	New Century Global	Chengdue, China	NA	1 700 000 sq. metre	2013
BRIDGES					
World's Longest (Two Bridges)	Lake Pontchar-train Causeway	La, U.S.A.	$ 26.9 million (1969 span)	38.4 km	1969
World's Longest (Suspension Bridge)	Akashi-Kaikyo	Kobe-Naruto, Japan	$ 4.3 billion	1991 metre	1998
World's Longest (Cable- Stayed Bridges)	Russky Bridge	Vladivastok Russky Island	NA	1104 metre (longest span)	2012
DAMS					
World's Largest - Volume Embankment	Tarbela	Pakistan	NA	148.5 million cu. m.	1973
World's Largest - Capacity Reservoir	Nalubaale	Uganda	$ 60 million	20.5 billion cu. m.	1954
TUNNELS					
World's Longest Water Tunnel	Delaware Aqueduct	New York State	$ 149 million (Not including design cost)	135 km	1944
World's Longest Railway Land Tunnel	Seikan	Japan	$ 5.3 billion	33.5 miles	1985
World's Longest Railway Channel Tunnel (Under Sea)	Channel Tunnel	Britain France	$15 billion	31.04 miles	1994
World's Longest Vehicular Tunnel	Laerdal	Norway	$114 million	24.5 km	2000

Source: 1. ENR: Construction Facts, Nov. 2003, McGraw-Hill Cos. Inc.
      2. Accessed websites in 2013 for World's Tallest Building, Cable-Stayed Bridges and Largest Floor Area

to three weeks per storey. With the use of latest formwork and ready-mix concrete technology, this time can be reduced to about one week. To quote an example, the structure of a 45-storey City Tower Hotel in Tel Aviv, was constructed at the rate of one storey after every five days. A German ready-mix supplier poured over 16 000 m³ of concrete within 24 hours for a 8.5 ft thick reinforced concrete mat foundation. The pour involved 300 workers; four 32-m trucks mounted telescope conveyors, four 42-m concrete boom pumps and one 52-m boom pump. In another location in Germany, over 1700 m³ concrete for a foundation work for one of the tallest buildings in Europe was poured in a 78-hour period by 90 ready mix trucks operating from six ready mix plants. Way back

Table 1.2

Some of the World's Largest Projects and Program

Country	Name	Cost ($ billion)	Start-Completion
Egypt	South Valley Development Project	90	1997–2017
16 Nations Partnership	International Space Station	60	1993–2008
China	South-to-North Water Diversion Project	48	Phase-I (2002–2010) Phase-II (2050)
Iraq	Rebuilding	29	2003
Libya	Great Man Made River Project	25	1984
China	Three Gorges Dam	24.6	1993–2009
China	Beijing Olympics	3.2	2008
U.S.A.	Louisiana Coastal Restoration Program	15	1990
Japan	Expansion of Kansai International Airport, Osaka	15	1999–2007
U.S.A.	Central Artery/Tunnel-Boston	14.6	1993–2005
China	Gas Pipe Line	8.5	Oct. 2003
U.K.	Channel Tunnel Rail Link	8.5	1998–2007
Lesotho	Highlands Water Project	8	1984–2000
Florida	Comprehensive Everglades Restoration Plan	8.4	1995–2025
Norway	Ormen Lange North Sea Gas Development	8	2003–2007
Belgium	Dutch High Speed Rail	7	2000–2006
Madrid-Lerida	Spanish High Speed Rail (AVE)	7	2006
Japan	Chubu International Airport	7	2000–2005
U.S.A.	Nuclear Tank Waste Remediation System	6.9	2000–2017
China	Hong Kong Waste Rail Line	6.6	1998–2003
Ireland	Dublin Metro	6.5	2000–2016
India	Golden Quadrilateral Highway Project Part-1 (3600 miles)	6	1998–2003
U.S.A.	Third Water Tunnel New York	6	1972–2020
Greece	Athens Olympics	5.7	1998–2004
Russia	Northern European Pipeline	5.7	2002–2009
Atlanta	Hartsfield Airport Expansion	5.4	2001–2010
U.S.A.	East Side Access Project	5.3	2002–2011
Taiwan	Kaoshsiung Metro	5.1	2001–2005

Source: ENR: Construction Facts, Nov. 2003, McGraw-Hill Cos. Inc.

Table 1.3

Some of the World's Largest Construction Machines Capabilities

S. No.	Machine Type	Model	Introduced Year	Capacity	Horsepower (hp)
1.	Bulldozer	Komatsu D575A-3 Super Dozer	2001	Blade 90 cu yd	1,150
2.	Truck	Caterpillar 797 B	2002	Payload 380 tons	3,370
3.	Excavator	Terex RH-400	1997	Shovel 57 cu yd or 90 tons	4,400
4.	Cable Shovel	P&H 4100XPB	1999	Shovel 82 cu yd or 100 tons	4,555
5.	Wheel Loader	Le Tourneau L-2350	2000	Bucket 57 cu yd or 80 tons	2,300
6.	Scraper	Caterpillar 657 E	1984	Bowl 44 cu yd (heaped)	1,045
7.	Paver	ABG Titan 525	2002	Hopper 17.5 tons, Paving width 52 ft 10 in., Paving thickness 19 in.	352
8.	Grader	Caterpillar 24H	1996	Length of Blade 24 ft	500
9.	Tower Crane	Kroll 1000	1978	Lift 264 tons @144-ft radius, Max. height under hook 311 ft 8 in.	
10.	Lattice-Boom Crawler Crane	Lampson LTL-2600	1994	Lift 1,543 tons @164-ft radius with 341-ft boom	3,400
11.	Telescopic-Boom Truck Crane	Liebherr LTM-1800	1988	Lift 875 tons @10-ft radius (basic boom and 176-ton counterweight), Max. lift height 479 ft	978
12.	Tunnel Boring Machine	BENTON'AIR pressurised slurry TBM	2001	14.87 m. cutting head diameter	4,691

Source: *ENR: Construction Facts*, 2004, McGraw-Hill Cos. Inc.

during 1982–84, an Indian company using pre-cast technology erected five-residential apartment superstructures per day in Baghdad. The new materials in the market that have added new dimensions to construction practices which include: curtain walls, structural glazing sheet, aluminum replacing wood, high performance concrete (going up to 100 MPa), high strength reinforced and structural steel, multi-variety customised pre-cast members, multi-utility chemical admixtures and large varieties of finishing products and utility components.

❑ 1.2 CONSTRUCTION SCOPE

1.2.1 Construction Market

The market of the construction business includes both international as well as domestic markets. Its profitability, like any other business, fluctuates according to the law of demand and supply.

International export market. There are about 225 top international companies that compete with each other for the global construction tenders. Despite some global upheavals and uncertainties, the world construction market showed a gradual rise in revenue from 2002 to 2011. Since the beginning of the new millennium and upto year 2011, the international construction market, as reported by ENR, ranged between 116 billion to 450 billion dollars per annum.

Global market of top 225 international companies (revenues US$ in billions)

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
US$ billion	116.5	139.8	167.5	189.4	224.4	310.3	382.4	383.8	383.7	453.0

For ENR's Top 225 International Contractors, 2001 was a down year. International revenue for the Top 225 fell 8.1% to $106.5 billion from $115.9 billion in 2000 and 11.5% from 1999's high of $118.7 billion. The market reached the $116 516.5 mark in 2002. Since the terrorist attacks of September 11, 2001, on New York City and Washington, D.C., followed by the Afghanistan and Iraq conflicts, the global construction market is going through an uncertain period. In some countries like India and China, the construction is booming but in the other countries like USA, the economy is softening and it is having its effect on the international construction market. **Table 1.4** shows how the international contractors shared the export market in the years 2009–2011.

In the international market, building, transportation and petroleum supply activities constitute the major areas in the business. The revenues generated by different activities in the global market in the years 2009–2011 are given in **Table 1.5**.

Global infrastructure market. The global market (demand) over the next 20 years for infrastructure is forecasted to be US$ 65 trillion. China is the largest infrastructure market in the world accounting for 40% of global infrastructure demand. Over the next few years, growing markets for infrastructure are Brazil, India, Indonesia and Turkey, which are expected to account for around 20%–25% of the world market. The US infrastructure market is about 15% of the world market. (*Source*: Global infrastructure market, accessed on September 01, 2012)

Infrastructure projects are the key drivers of economic growth. India is now emerging as the third largest economy in the world next only to the US and China but inadequate infrastructure is dragging down India's economic growth.

Table 1.4

The Top 225 International Construction Companies Years 2009 to 2011: International Regions of Market Analysis

International Regions	Year 2009		Year 2010		Year 2011	
	Revenue ($ million)	Percentage	Revenue ($ million)	Percentage	Revenue ($ million)	Percentage
Canada	13 402.0	3.4	13 383.4	3.5	13 003.2	3.4
USA	41 659.5	10.7	34 878.2	9.1	32 612.9	8.5
Latin America	21 761.9	5.6	24 819.9	6.5	30 425.2	7.9
Caribbean Island	2077.8	0.5	2292.5	0.6	3620.7	0.9
Europe	114 106.2	9.3	100 806.6	26.3	94 183.4	24.5
Middle East	77 470.6	19.9	77 557.0	20.2	72 434.0	18.9
Asia/Australia	68 532.5	17.6	73 183.1	19.1	76 639.7	20.0
North Africa	21 622.9	5.5	27 520.9	7.2	29 540.4	7.7
South/Central Africa	29 262.2	7.5	29 290.7	7.6 31	051.8	8.1
All Others	12.3	0.0	49.2	0.0		

Domestic infrastructure market.   In most of the countries, the domestic market far exceeds the international market.

In India, the 11th Five Year Plan (2007–2012) targets were an average 8%–0% annual growth (relative to 5.08% actual targeted in 10th Plan). These were planned to be maintained at 10% in the 12th Plan in order to double per capita income by 2016–17. The most critical short-term barriers to economic growth are absence of world-class infrastructure (power in particular). Focus on quality and efficient infrastructure services is essential to realise the full potential of the growth impulses surging through the economy. Investment requirements for infrastructure during the 11th Five Year plan were revised to be around Rs. 2 054 205 crore. While nearly 60% of these resources would come from the public sector, the balance would need to come either from the exclusive private sector and/or from public-private-partnership (PPP), wherever feasible. Investment requirements by 2012, estimated by the Committee o n Infrastructure, in some of the key infrastructure sectors are: Rs. 220 000 crore for modernisation and upgradation of highways; Rs. 40 000 crore for civil aviation; Rs. 50 000 crore for ports; and Rs. 300 000 crore for the railways. The power sector outlay is Rs. 658 630 crore.

In India, sector-wise investments in 10th Five-Year Plan and 11th Plan, and Projected infrastructure Investment during the 12th Plan are tabulated in **Tables 1.6** and **1.7**.

Table 1.5

**Top 225 International Contractors at a Glance
Nature of Work Handled In International Market**

Type of Work	Revenue ($ mil)			Percentage of Total		
	2009	**2010**	**2011**	**2009**	**2010**	**2011**
Building	94 067.6	85988.3	96102.1	24.1	22.4	20.1
Manufacturing	6916.9	3805.6	6083.1	1.8	1.0	1.2
Industrial	23001.3	20601.5	29569.0	5.9	5.4	6.5
Petroleum	90837.8	91421.5	104234.1	23.3	23.8	23.0
Water	14234.2	11221.8	15.352.9	3.6	2.9	3.4
Sewer/Waste	5813.9	6289.7	7087.9	1.5	1.6	1.6
Transportation	104092.2	112342.0	121439.7	26.7	29.3	26.8
Hazardous Waste	549.2	486.0	827.3	0.1	0.1	0.2
Power	26723.5	35694.4	47043.1	6.9	9.3	10.4
Telecommunication	3937.3	2685.8	5946.4	1.0	0.7	1.3
Other	19833.7	13249.9	29.331.1	5.1	3.5	6.4

Source: ENR, McGraw-Hill Cos. Inc. (August 20, 2007 and August 18, 2008)

1.2.2   Construction Projects Stakeholders

Project stakeholders or participants are the individuals and organisations who are actively involved in the project's outcome. Some stakeholders may have competing and conflicting expectations. Key stakeholders in a typical construction project include: sponsors, business promoters/owners, project managers, project teams, architect-engineering associates, construction management consultants, banking and financial institutions, input suppliers, contractors and the affected people. It is the project manager who manages the expectations of the stakeholders. To quote an example, stakeholders of a typical medium size BOT highway project are shown in **Figure 1.1**.

The agencies supporting the construction industry include but are not limited to the following:

- Construction business promoters like government bodies, public and private enterprises for real estate and industrial development, and other similar agencies;
- Construction management consultant firms;
- Architect-engineering associates;
- Construction manpower recruitment and training agencies;
- Construction materials developing, manufacturing, stocking, transportation and trading firms;
- Construction plant and machinery manufacturing, distributing, and repair and maintenance organisations;

Tables 1.6

Sector-wise Investments (Rs. in Crore): 10th, 11th and 12th Five-Year Plan

Infrastructure Requirements	10th FY Plan		11th FY Plan		12th FY Plan
	Original Projections	Actual Investments	Original Projections	Revised Projections	Original Projections
Electricity (incl. Non-Conventional)	2,91,850 (33.49)	3,40,237 (37.55)	6,66,525 (30.42)	6,58,630 (32.06)	12,57,604
Roads & Bridges	1,44,892 (16.33)	1,27,107 (14.03)	3,14,152 (15.28)	2,78,658 (13.57)	4,90,272
Telecommunications	1,03,365 (11.86)	1,01,889 (11.25)	2,58,439 (12.57)	3,45,134 (16.80)	10,11,692
Railways (incl. MRTS)	1,19,658 (13.73)	1,02,091 (11.27)	2,61,808 (12.73)	2,00,802 (9.78)	2,96,393
Irrigation (incl. Watershed)	1,11,503 (12.30)	1,06,743 (11.78)	2,53,301 (12.31)	2,46,234 (11.99)	3,98,642
Water Supply & Sanitation	64,803 (7.44)	60,108 (6.63)	1,43,730 (6.99)	1,11,689 (5.54)	1,85,244
Ports (incl. inland)	14,071 (1.61)	22,997 (2.54)	87,995 (4.28)	40,647 (1.98)	1,05,034
Airports	6,771 (0.78)	6,893 (0.76)	30,968 (1.51)	36,138 (1.76)	66,277
Storage	4,819 (0.55)	5,643 (0.62)	22,378 (1.09)	8,966 (0.44)	25,736
Oil & gas pipelines	9,713 (1.11)	32,367 (3.57)	16,855 (0.82)	1,27,306 (6.20)	2,62,345
Total Investments	8,71,445 (100)	9,06,074 (100)	20,56,150 (100)	20,54,205 (100)	40,99,239

Source: India's Planning Commission.

Table 1.7

Construction Sector: Micro Aggregate

Macro-Variable	2006-07	2007-08	2008-09	2009-10	2010-11
GDP from construction (Rs. lakh crores)	2.85	3.15	3.333	3.56	3.85
Share of GDP (%)	8.0	8.1	8.0	7.9	7.9
Growth Rate for GDP in Construction (%)	10.3	10.7	5.4	7.0	8.1

Source: Handbook of Statistics, RBI 2010-2011.

- Banking and financial institutions;
- Risk insurance and legal services companies;
- Construction quality assurance and research and development establishments;
- Contractors and contracting firms; and
- Project manager and his team.

There are six main agencies actively associated with the execution of major works. These are: client, construction management consultants, architects-engineering associates, financial institutions, input suppliers and contractors.

Figure 1.1

Construction Participants in a Typical BOT Project
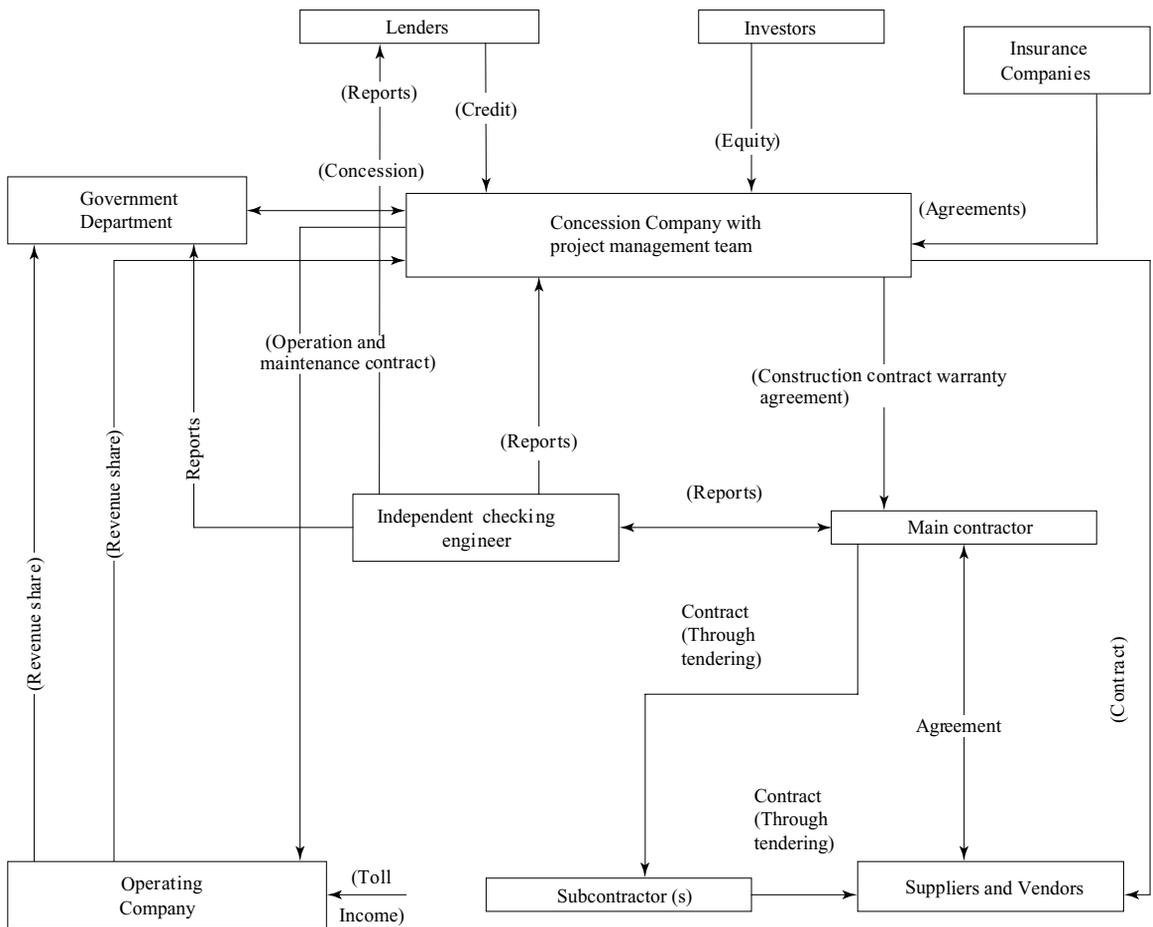
Business promoter/client.   He is the potential owner of the construction facility. He sponsors the construction works and ultimately utilises them. A client can be a government body, a public or private agency, an entrepreneur, or a builder, or an investor. It is the client who undertakes developmental facilities like housing, roads and power plants with certain motives or long-term aims. It is he who finances their construction, and utilises the facility constructed. It is on his demand that the market forces react. Thus, in reality, it is the client who is the promoter of the construction business.

Construction management consultants.   The emerging trend these days among the clients is to hire the construction management consultants for rendering certain services on contract basis for the entire life of the project. The nature of tasks assigned to this group by the clients varies, but it generally includes the following:

- Project feasibility, including cost estimates;
- Site survey and soil investigations;
- Scrutiny and coordination of designs and drawing work;
- Estimating, initial planning, and budgeting costs;
- Processing pre-qualification of construction agencies, tendering, and awarding contracts to the successful bidders;
- Designing project organisations for executing works and developing standard operating procedures and systems;
- Developing detailed construction plans, project schedules and performance measuring standards; and
- Supervising works, including administration of contracts and controlling of project time, cost and quality objectives.

Architect-engineering associates.   An architect is an individual who designs the buildings, landscapes and other artistic features. The engineers associated with architects develop structural, electrical, mechanical and other specialist systems and designs. Architect-engineering associates are the firms employing both architects as well as engineers to provide complete design services under one roof. Some of these firms also provide construction management services.

   The architect-engineering firms are frequently required to coordinate with the construction management consultant/manager, who knows the project needs, and is required to scrutinise designs and drawings from the construction point of view. Construction consultants, with all their construction expertise, can render valuable guidance and advice to the design team, especially when the latter has to finally approach them for approval.

Banking and financial institutions.   Money is at the core of all business activities and construction being a capital intensive business, generally it also operates under money constraints. There are a number of financial institutions that provide long term finance to the construction agencies for implementing projects. The financial institutions provide direct and indirect financial assistance. Direct financial assistance includes: Term Loans, Foreign Currency Loans, Subscription to Equity Shares and Seed Capital. The indirect financial assistance helps the industrial units to obtain finance/credit in the form of Deferred Payment Guarantee, Guarantee for Foreign Currency Loans

and Underwriting. There are global funding bodies and national financial institutions. The global funding bodies include: World Bank, Asian Development Bank and similar agencies. In India, the major financial institutions are:

- Housing and Urban Development Corporation Ltd.,
- Industrial Finance Corporation of India,
- Industrial Development Bank of India,
- Industrial Credit and Investment Corporation of India,
- Other all-India institutions,
- State Financial Corporations, and
- State Industrial Development Corporations.

Input suppliers.   Construction process needs resource input. Construction inputs exist in the form of men, materials, machinery and money. The workforce connected with construction includes architects, engineers, managers, technical and non-technical staff, highly skilled operators, and skilled and unskilled manpower. Construction activity requires a wide variety of materials, which form a substantial part of the entire construction cost. Induction of construction plant and machinery has revolutionised construction practices by adding the speed factor and reducing the need for difficult-to-manage manpower.

Construction input resources are converted into construction facilities by using the standard construction practices and management methodologies. This process of input procurement, conversion and management of resources covers a wide spectrum of the construction business activity.

Contractors.   Construction contractors form the backbone of the construction business as they execute most of the construction work. In the competitive construction business, which requires special resources for different types of construction work, the contractors generally tend to specialise in a particular area of construction. From this functional angle, the contractors can be classified into the following categories:

a. General contractors,
b. Building contractors,
c. Specialist contractors for various types of heavy infrastructure construction work such as: highways, bridges, dams, marine works, etc.,
d. Specialist (mostly turnkey) contractors for various categories of industrial works like power plants, process industries, and so on,
e. Specialist utility services contractors who include: electrical contractors, water supply and sewage disposal contractors, HVAC (heating, ventilation and air-conditioning) contractors, and so on.

1.2.3   Industry Contribution to Economic Growth

Construction Contribution. Construction is an ever growing activity across the globe. From economics angle, the construction industry is that sector of economy that plans, designs, constructs, maintains, alters and repairs physical immobile structures and facilities like building complexes,

transportation networks, processing plants, manufacturing installations, power plants, transmission lines, ports and harbours, water supply and sewerage disposals, and other utility works involving civil, mechanical, electrical, telecommunication and other skills. It is an aggregate of businesses that are closely linked with the physical constructions, repair and maintenance of buildings, infrastructure works and industrial facilities involving the application of various engineering skills.

The construction industry is one of the main contributors to the growth of the economy of a country. It generates nearly half of fixed capital formation, employs large work force, and has national and international markets. The construction industry undertakes a wide variety of works spread over different regions. In a given accounting year, some works are spilling over from the previous year; some are completed during the year, while some overflow to the next year. In order to measure their output at national level, a number of output measuring devices are employed. These outputs form part of the national accounting, statement, generally published annually. The information in these construction statements generally falls under three main heads i.e. value added in construction, fixed capital formation in construction and gross construction output. Value added in construction is usually referred as the contribution of the construction industry to gross domestic product (GDP). The GDP is the combined market value of all goods and services produced by an economy in a year. In order to counter the effect of inflation, the GDP at constant price is adjusted against a base period. This contribution in GDP, which amounts to the sum of income payments, includes salary and wages of employees, interest on borrowed capital, net rents paid, profit and allowances for depreciation.

Capital formation in construction. Rlates to the total value of all new construction, addition and improvements in existing capital works but excluding repair and maintenance. Value Added in Construction, Fixed Capital Formation and Gross Construction Output are related as under:

Value added in construction industry = Value of new works + Value of improvements
+ Value of repair and maintenance
(It is the contribution of the industry to GDP)

Gross construction output = Value added in construction industry
+ Value of goods and services
(Obtained from other sectors of the economy)

Capital formation in construction = Gross construction output – Repair and maintenance

Economic contribution in India.   Among the emerging economies in the world, India recorded one of the highest growth rates in the year 2003–04; second only to China. In India, during the year April 2003–March 2004, construction growth in Real GDP was 6.1% and it has recorded 7.2% in 2006–07 (see details in **Table 1.8**).

The Indian economy is dominated by the services sector, which contributes more than half of GDP. The services include communication services, financial services, real estate and business services (including IT), community services and construction.

Employment potential in construction.   Construction is an employment spinner. It generates more employment than many other sectors. In India, during the 1980s, the overall annual employ-

Table 1.8

India's Growth Rate of Real GDP Percentage (at 1999–2000 Prices)

Sub-sectors	Growth rate (percentage)					Average of 2000-01 to 2007-08
	2003-04	2004-05	2005-06@	2006-07#	2007-08*	
Real GDP at factor cost	8.5	7.5	9.4	9.6	9.0	7.3
Contribution to GDP						
Agriculture and allied	10.0	NA	5.9	3.8	4.5	2.9
Industry	6.0	8.5	8.0	10.5	8.1	7.1
Services	8.8	9.9	11.0	11.2	10.7	9.0
Construction	12.0	16.1	16.5	12.0	9.8	10.6
Trade, hotels and restaurants	10.1	7.7	9.4	8.5	12.0	8.2
Transport, storage and communications	15.3	15.6	14.6	16.6	NA	13.7
Financing, insurances, real estate and business services	5.6	8.7	11.4	13.9	11.8	8.8
Community, social and personal services	5.4	6.9	7.2	6.9	7.3	5.8
Construction share in GDP	6.1	6.6	7.1	7.2	7.3	NA

@ Provisional Estimate; # Quick Estimate; * Revised Estimate; NA Not Available.
Source: Reserve Bank of India, Annual Report 2007–2008.

ment increased by 2%, whereas employment in the construction sector recorded an annual growth of about 7%. Further, the number of persons employed in the construction industry in India during the Year 2005, was assessed as 31 million (see **Table 1.9**).

All categories of labour employed in India in all sectors of the economy in the year 2004 were reported to be of the order of 364 million.

❑ 1.3 PROJECT CONCEPT AND FEATURES

1.3.1 Project Concept

The works carried out in any organisation can be divided into two categories i.e. new unique endeavour and routine operations. The completion time for a unique endeavour can vary from a few hours to many years, and the cost can range from low to very high. A project is a new unique endeav-our undertaken to achieve specified objectives. 'New' implies that it is different from the management of routine operations, 'unique' means that it is not done before (at the same location and with the same resources) and it is subject to risks and uncertainties. Transient endeavour implies

Table 1.9

Manpower Assessed in Construction Sector

S. No	Category	1995		2005		Growth % in 10 Yr.
		No.	Percentage Total	No.	Percentage Total	
1	Engineers	687,000	4.70	822,000	2.65	19.66
2	Technicians and Foremen	359,000	2.46	573,000	1.85	59.61
3	Secretarial	646,000	4.42	738,000	2.38	14.24
4	Skilled Workers	2,241,000	15.34	3,267,000	10.54	45.78
5	Unskilled Workers	10,670,000	73.08	25,600,000	82.58	139.92
	Total	14,603,000	100.00	31,000,000	100.00	100.00

Source: Report of a Working Group on Construction for India's Eleventh Plan..

that it is a temporary organisation created to attain specified objectives of completion time, budgeted costs and development specifications.

A project is a temporary endeavour or mission undertaken to create a unique products or services or results. Temporary nature of project means that it has well defined beginning and end. ISO 10006 defines project as: a unique process, consisting of a set of coordinated and controlled activities with start and finish dates, undertaken to achieve an objective conforming to specific requirements that include the constraints of time, resources, cost and product quality. Examples of a project include developing a new weapon system, conducting a feasibility study for setting up a factory, building a housing complex, constructing a highway, developing a commercial complex, or running an electioneering campaign. Management of the routine operations in an organisation falls in the category of operations management.

A project aims at accomplishing a development objective like creating a product or service or a specified outcome, hereafter referred as a 'Facility'. The project objective is to create a facility within specified constraints. The term 'facility', as used in this book, includes product, service or a specified outcome, which is the end result of a project.

Each project has a specified mission or a purpose to be achieved. It ceases after the mission is accomplished. A construction project mission is to create a desired facility like a housing complex or a fertilizer plant with predetermined performance objectives defined in terms of quality specifications, completion time, budgeted costs and other specified constraints. It is not a routine activity like the regular maintenance of buildings or roads. Management of a construction project mission entails the multi directional interaction of dynamic forces represented by its scope, time, resources, cost and quality. There is always a dynamic link on how to manage scope, resources, product quality and how to stay within time and budget limits. Despite diversities and multifarious activities, each project is an entity

Each project is unique in itself, and no two projects are ever alike. Even two similarly designed projects may differ from each other in one or more influencing factors such as: client and contrac-

tors, quality specifications, resources required, responsibilities assigned and the project environments. Each one of these factors may have a decisive effect on the development of the project.

1.3.2   Project Purpose and Types

These new unique endeavours can be need-based requirements of an organisation or business- related endeavours generally conforming to the implementation of a strategic program, or solving a problem of the owner/sponsoring organisation, or exploit an opportunity for commercial purposes. Broadly the projects, depending upon the purpose, can be divided into various types as shown in **Figure 1.2**.

Figure 1.2

Different Types of Projects
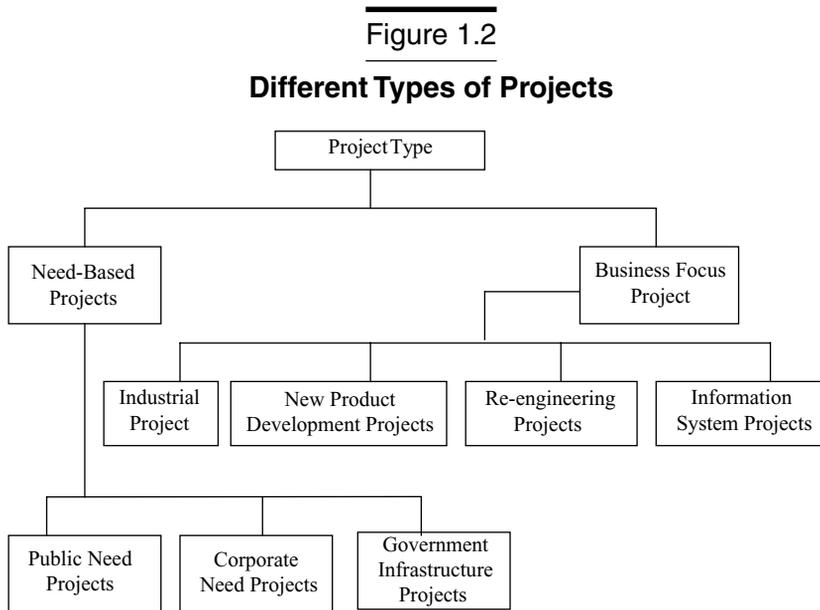
1.3.3   Project Maturity Level

Mature means fully developed or grown up. In the project context, maturity implies the extent and reliability to which a project scope of work can be defined in performing the specified objectives successfully. Depending upon maturity level, the projects can be broadly classified into the following four categories:

- *Highly matured projects*. These have clearly defined requirements and the well-established accomplishment methods and processes, which can be defined qualitatively and quantitatively in terms of design, specification, BOQ and planned progress. For example, most of the construction projects fall in this category. These projects can be designed, quantified, planned and monitored effectively. There are insignificant risks involved in achieving the objectives.
- *Moderately matured projects*. These have clearly defined requirements but delivery process is not very clear. For example, development and consultancy projects. These have Low Value Risks in achieving objectives.

- *Low maturity projects*. These have clear requirements but delivery process is unknown. For example, new product development projects. These have Medium Value Risks in achieving objectives.
- *Poor maturity projects*. These have ill-defined objects and unclear delivery process. For example, advanced R&D complex projects have High Value Risks in achieving/changing objectives.

1.3.4 Project Types

Depending upon the project scope, maturity and the degree of risk levels, construction-related projects can be further divided as under:

		Type of projects	
	High Risk	Type-2: PPP projects	Type-4: R&D projects
Risk	**Low Risk**	Type-1: Construction projects	Type-3: Consultancy projects
		High Maturity	**Low Maturity**

Matrurity Level

1.3.5 Program vs. Project

A program at the macro level comprises of one or more related projects. These projects are usually a part of an overall strategic programme. For example, a government decision to provide compulsory education at primary level to the children of its citizens is a strategic programme with social objective. This compulsory education involves a number of region-wise programmes and each programme may have a number of projects like: construction of education buildings, provisioning of training aids and staffing with trained personnel.

A programme is managed to achieve its overall strategic objectives through the implementation of the projects. Portfolio management in a multi-projects environment refers to managing investments to achieve overall programme strategic objectives, by identifying, prioritising and managing resources related to the works.

1.3.6 Project and Product Life Cycles

A project life cycle is a set of sequential phases of a project from its initiation to its closure. The product is a facility that is produced by the project. A typical project development life cycle can be divided into three sequential or overlapping stages, i.e. (a) project development management or facility development stage (which includes project formulation, design, planning, execution, monitoring and commissioning), (b) facility operation/utilisation stage and (c) facility utility declining till it ends up with termination stage. The time between the start of the initiation stage of its development to its dead end represents the Project New Venture Product Life Cycle. It includes the project facility(s)

development period, the facility/product/deliveries intended utilisation period, and the product determination stage. In the final phase, the product may be redesigned or modified or downgraded or discarded. The life cycle of a typical New Endeavour Product Life Cycle is depicted in **Figure 1.3**.

Figure 1.3

The Project Life Cycle of a Typical New Product
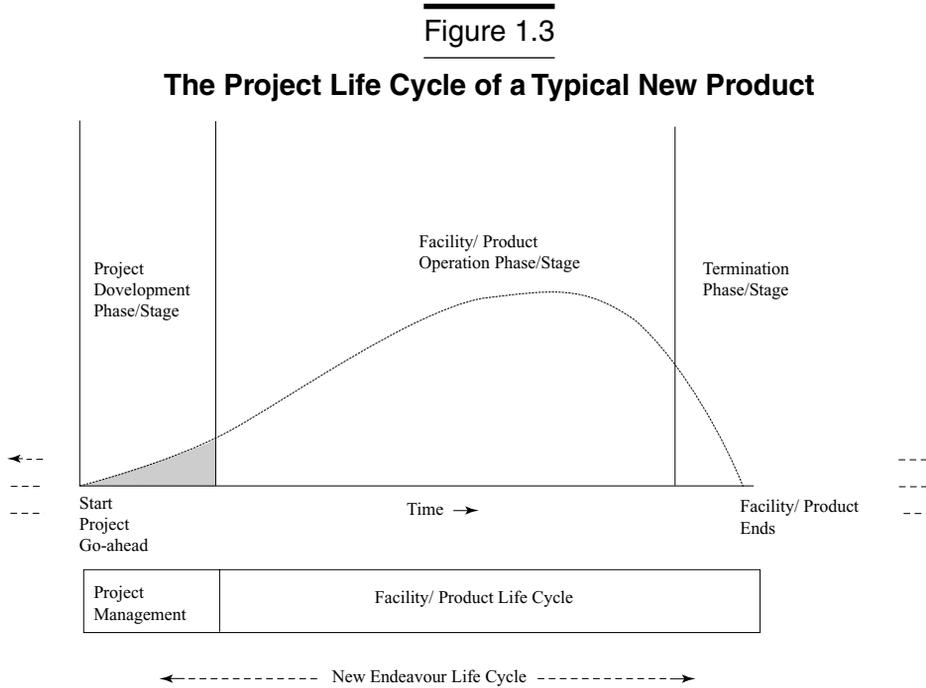
A business related project life cycle = Facility development period
+ Facility operations period + Facility declining period

A real estate project life cycle = Facility development period
+ Property utilisation period + Property declining period

❑ 1.4   CONSTRUCTION PROJECT CHARACTERISTICS

1.4.1   Construction Project Definition

In the project context, construction implies designing building, installation and commissioning of items of civil, mechanical, electrical, telecommunication and other utility works, necessary for building a specified construction-related facility or service.

A 'construction project' is a high-value, time bound, special construction mission of creating a construction facility or service, with predetermined performance objectives defined in terms of : quality specification, completion time, budgeted cost and other specified constraints. Each mis-

sion starts with a project go-ahead and ends with the accomplishment of the mission purpose. The project's unique construction mission is accomplished within the complex project environments, by putting together human and non-human resources into a temporary organisation (like a special mission army operation in the war), headed by a project manager. The term 'project' used hereafter in this book, relates to 'Construction Project', unless otherwise stated.

1.4.2 Construction Project Development Phases

A construction project concept analysis starts with feasibility analysis and it is followed by go-ahead decision. It is completed when its specified product/facility is ready to perform its designed function. The period between the start and completion of the facility is called Construction Project Development Cycle.

A generic construction project development cycle can be divided into generally sequential four phases or stages determined by the control needs of the project. These phases are Concept Analysis, Planning and Procurement, Implementation or Execution, and commissioning after completion. Commencing from the concept analysis phase to its completion phase, a typical construction project's four sequential stages or phases are shown in **Figure 1.4**.

Figure 1.4

Typical Sequence of Developm Phases in a Construction Project
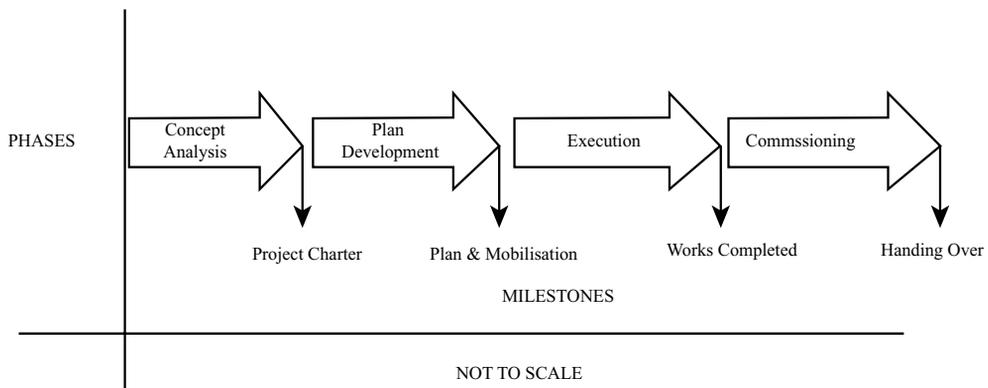
1.4.3 Construction Project Classification

In general, construction projects include numerous interdependent and interrelated activities and employ huge resources of men, materials and machines. They involve heavy investments of million to billions of dollars and carry a high degree of risks. They require a high level of technology management of construction projects and differ from the management of ongoing steady-state business-related enterprises in many ways (see Section 1.6.3). Universally, the execution of major construction

-intensive capital works is undertaken by projectising them, that is, by organising them into one or more construction projects for the implementation. The purpose of the construction project mission is to create a facility or provide a construction-related service. Construction projects come in many forms with varying purposes. There is no simple method to classify them. These projects can be categorised by the nature of construction works, the mode of execution, cost and time constraints, the inherent uncertainty (maturity level) or a combination of these, as given in **Table 1.10**.

Broadly, depending upon nature of construction facility, the major construction projects are grouped into 'Building construction', 'Infrastructure construction', 'Industrial construction' and 'Special-purpose' projects.

Table 1.10

Classification of Construction Projects

Project Classification Basis	Classification Breakdown
1. Nature of construction facility	'Building construction', 'Infrastructure construction', 'Industrial construction' or 'Special-purpose projects'.
2. Nature of work	Repetitive Works or Nonrepetitive Works
3. Mode of execution	Departmental or Contractual
4. Nature of construction contract	Cost plus, Item Rate, Lump-sum, Turnkey or BOT
5. Completion time	Long duration program (over 5 years)
	Medium duration projects (3–5 years)
	Normal duration projects (1–3 years)
	Special short-term projects (less than 1 year)
6. Budgeted cost (Indian public sector)	Mega value programme/projects (over Rs. 1000 crores)
	Large value projects (Rs. 100 crores to 1000 crores)
	Medium value projects (Rs. 20 crores to Rs. 100 crores)
	Small value project less than Rs. 20 crores
7. Maturity level	Insignificant risk, Low value risk, Medium value risk, High value risk.
8. Need based projects	Public need projects, Corporate need projects, Commercial projects, Re-engineering projects.

Building construction projects.   Building works include all types of buildings such as: residential and commercial complexes, educational and recreational facilities, hospitals and hotels, estates and offices, warehouses and shelters. 'Buildings' constitute the largest segment of construction business. The building business serves mankind by providing shelter and services for its habitation, educational, recreational, social and commercial needs. The building works are mostly designed by the Architect-Engineering firms, and are financed by governments, public and private sectors.

Infrastructure construction projects.   Economic development needs infrastructure services. These services are broadly divided into physical and social services. Infrastructure physical services include: electricity, transport, irrigation, housing, water supply, sanitation etc. Infrastructure social services cover education, health care, recreation, banking, financial institutions etc.

Infrastructure of physical construction services has a direct impact on the growth and overall development of an economy. These are capital intensive and heavy equipment-oriented works, which involve the movement of a large quantity of bulk materials like earth, steel and concrete. These works include dams and canals, highways and airports, railways and bridges, oil/gas pipelines and transmission lines, large water supply and sewage disposal networks, docks and harbours, nuclear and thermal power plants, and other specialist construction activities which build-up the infrastructure for the growth of the economy. These works are designed by the specialist engineering firms.

Industrial construction projects.   These works include: construction of manufacturing, processing and industrial plants like steel mills, petroleum refineries and consumer-goods factories. These works involve heavy investment and are highly specialised. Industrial Constructions are financed by government, public and private enterprises.

Special-purpose construction-related projects.   These include environmental protection works, emergencies, remedial works, utility services, and complex key operations.

1.4.4   Construction Project Performance Objectives

There are many factors that determine the outcome of a construction project but the five main parameters that can sufficiently define a construction project are: scope, quality, resources, completion time and cost.

1. Scope defines the deliverables. The deliverables are measured in terms of the quantities of work and the nature of the tasks involved in the execution of the project. The quantity of work is surveyed from the design and drawings. Nature of tasks determines the complexity of the work. Complexity increases as the number of dissimilar tasks increase and it decreases if the tasks are repetitive (or similar in nature).
2. Quality of the product to be achieved in accomplishing tasks is stated in terms of construction design, drawings and specifications.
3. Resources are necessary to perform the work. Resource productivity measures the efficiency with which the resources are utilised.
4. Completion time depends upon the speed with which the project is to be executed.
5. Cost is the budgeted expenditure, which the client has agreed to commit to creating/acquiring the desired construction facility.

The above five parameters are interactive, that is, each parameter is a function of the other. In addition to the above five parameters, there are many other features/variables that are associated with project performance. These additional parameters include: project organisation, culture, stake holder's interest, contractor's performance capability, etc.

The evaluation and balancing of interrelationship among the five interactive project parameters is a complicated process. However, in a given project, the scope and quality of work in terms of quantity and specifications are specified and these parameters are not subject to change (unless scope changes substantially). Costs and resources are correlated. Therefore, for a given quality, in such situation, scope, time, resources, cost and connected risks are the core parameters. These parameters are interlinked and must be kept in balance to achieve project objective efficiently and effectively within the changing environments. (also see **Figures 1.5 and 1.11**). The project planning, scheduling and controlling methodology employed for managing scope, time, resources and cost, within the changing environments, is loosely called the 'project management techniques'. This book includes these techniques.

Figure 1.5

Interactive Project Parameters
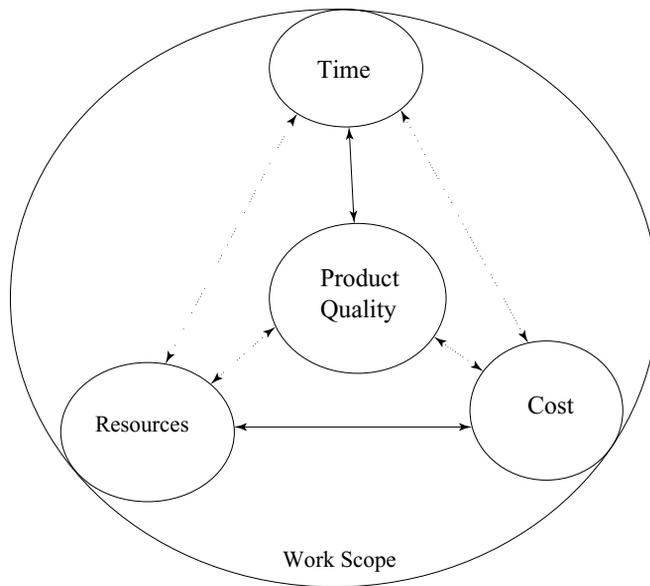
1.4.5 Construction Project Environment

A project exists in association with its internal and external risk-prone environment, which undergo frequent changes. The internal environment of the project includes: corporate objectives, stakeholders' interests, resources, problems, conversion processes and people management. The external environments are associated with changes in social, political, legal, economic and financial factors.

These internal and external environments have inherent uncertainties and are risk-prone. Most of the construction projects have one or more of the following characteristics/uncertainties associated with them:

- Details of work are not precisely defined;
- Scope of work gets modified during execution;
- Nature of work varies from job to job;
- Site of works is located in remote areas;
- Places of works are spread out;
- Resource requirements and organisation of works differ with each task;
- Investments involved are large and the decisions entail risks;
- Performance is sensitive to the unexplored site geology, uncertain weather and unforeseen natural calamities; and
- Rapidly changing technology, fast moving economic conditions and susceptible environments add new dimensions to the complex nature of construction projects.

The success of a project depends upon the management of these risk-prone changing environments within the framework of project objectives. Project risk management during implementation phase is covered in **Chapter 17**.

1.4.6   Common Attributes of Construction Projects

While no two projects are alike, they have certain common attributes. These are:

1. Interactive parameters (see **Figure 1.5**): In the project development phase, initially there is a gradual build up in the use of resources from the start of the project. It is followed by a long duration plateau during the execution/construction phase, where most of the expenses are incurred. Towards the end, there is a rapid run-down as the project draws to a conclusion (see **Figure 1.6**).

   The probability of successfully completing the project is minimal at the start of the project and the risk is highest. The probability of successful completion (balance works) gradually increases and the risks reduce as the work progresses. The implications of design changes in the scope of work are lowest at the start of the project but increase exponentially as the work progresses (see **Figure 1.7**).

2. The ability of the stakeholders to influence the scope of work of a project within a budgeted cost is highest at the start and gets progressively lower as the project continues (see **Figure 1.8**).

❑ 1.5   CONSTRUCTION PROJECT DEVELOPMENT: PHASES AND PROCESSES

1.5.1   Construction Project Phases and Processes

Phases.   In a construction project, works are divided into phases for exercising control. A typical construction project comprises of four phases, i.e. project concept analysis phase, planning and

Figure 1.6

Project Formulation, Planning and Design, Execution and Control, and Close-up Phases
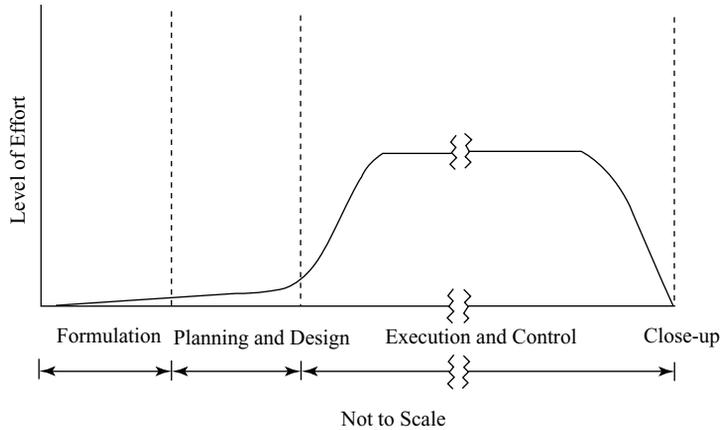
Figure 1.7

Risks and Probability of Project Completion
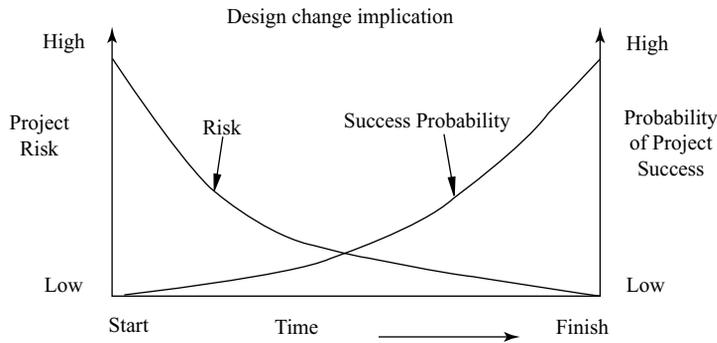
construction procurement phase, construction (execution and control) phase and close-up (including demobilisation) phase. These phases are generally sequential but may overlap in some situations (see **Figure 1.9**).

Processes. Each phase, depending upon its deliverables, contains a single or a group of processes. A process is an action or a set of actions that are performed to bring about a desired result. Each process is fed with inputs; these inputs are processed using tools and techniques to produce outputs. The output of a process is generally followed with the start of one or more of the subsequent generally sequential processes. The phases with processes in a typical construction project are outlined below; generally these project processes overlap (see **Figure 1.10**).

Figure 1.8

**The Ability of the Stakeholders to Influence the Scope
of Work of a Project within Budgeted Cost**
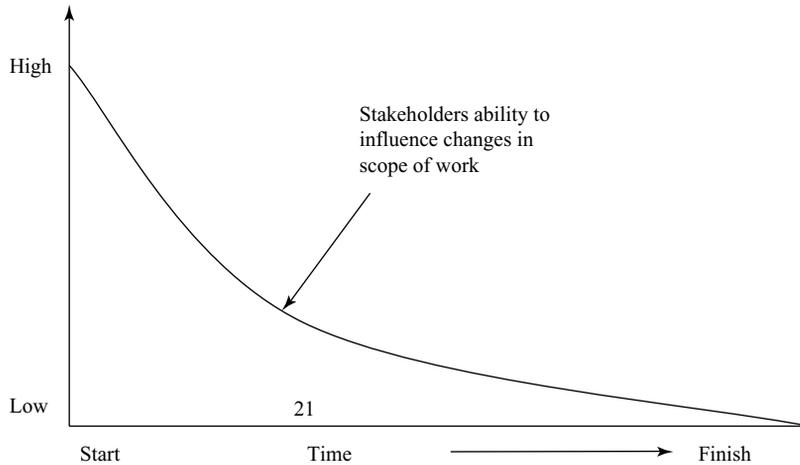
Figure 1.9

Project Construction Management Phases
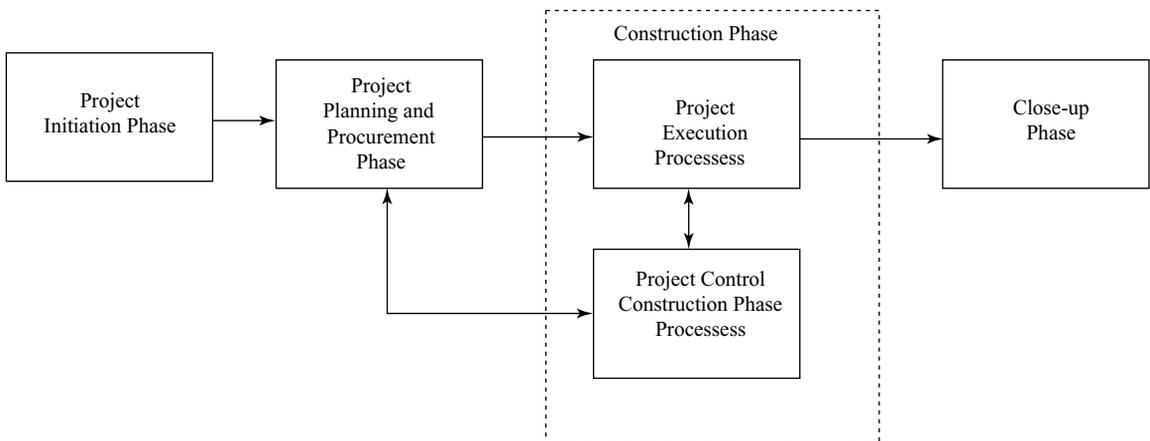
The processes in a construction project can be generally divided into two categories, i.e. project management-related processes and technical management related processes. Project management processes have the similarity but the technical management process differ from project to project.

The development phases and processes, relating to project phases, given in subsequent paragraphs, are concerned with management of projects and exclude the technical management related processes.

Figure 1.10

Processes in a Construction Project Life Span
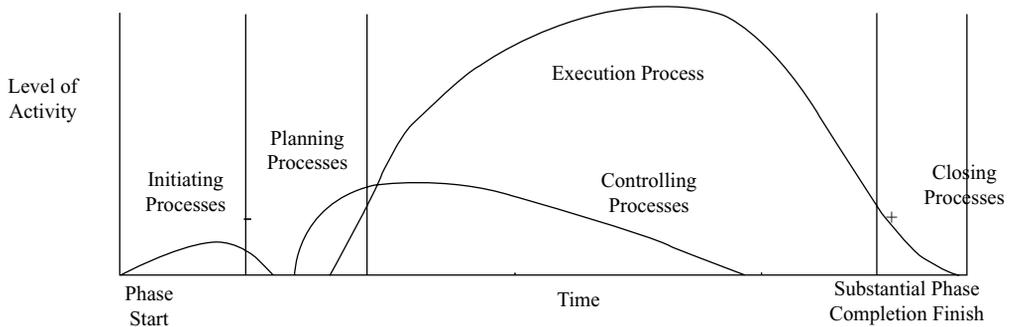
1.5.2 Processes in Construction Project Concept Analysis Phase

Processes in project concept analysis
Need analysis
Feasibility study
Project investment analysis and appraisal
Project implementation strategy

Project Concept Analysis of a project is a complex process. It involves developing the concept of the project, conducting feasibility study, undertaking investment appraisal and making the decision to invest in the project. The entire information is then presented in the form of a Feasibility Report which forms the basis for investment appraisal and decision-making. For larger projects, a Detailed Project Report is prepared after the investment decision is made, which is discussed in the later part of this book. The Project need analysis, Feasibility study, Investment Analysis and Appraisal and Project implementation strategy are outlined subsequent. (Readers may go through all these aspects covered in details in *Project Management Handbook*, **Chapter 2**, by Dr. Uddesh Kohli and Lt Col K.K. Chitkara, published by Tata McGraw-Hill.

Project needs analysis.   The needs of construction projects arise for various reasons. Some of these 'needs' include development of the infrastructure, setting-up an industry, expanding or diversifying the existing business activity, meeting the needs of society, an investment in real estate and so on.

In the construction business, the key to success lies in getting into the right business at the right time. Identification of such opportunities requires:

1. **Generation of ideas.** Brainstorming or similar techniques can facilitate in stimulating the flow of ideas.
2. **Monitoring the environment.** Basically, a promising investment idea enables a firm (or an entrepreneur) to exploit opportunities in the environment, by drawing on its competitive strengths.

3. **Corporate appraisal.** The important aspects to be considered under this include market image, market share, condition and capacity of plant and machinery, location advantage, track record, cash flows and liquidity, and dynamism of top management. A realistic SWOT appraisal of corporate strengths and weaknesses is essential for identifying investment opportunities, which can be profitably exploited.

Feasibility study.   The objective of the feasibility study, invariably, is to analyse the factors affecting the viability of a project and to present the findings with recommendations in the form of a project feasibility report for implementation. A feasibility report forms the basis for the investment decisions made by the project promoters, for the support extended by the financial institutions, for the clearance given by the appropriate approving authorities, and for giving an insight to the project manager into the techno-economic basis on which the project is approved.

The feasibility study evaluates project potential by examining the technical feasibility, economic viability and financial implications.

1. Proposed facility/product features.
2. *Demand survey:* It includes prospective customers, consumption pattern, existing market, government policy, demand forecast and sale potential.
3. *Technical studies:* These cover production process selection, construction methodology, location study, power and local resource availability, means of transportation, scope of work, wastage disposal arrangement, construction cost estimates, preliminary time plan, resource forecasts, outline project organisation, and statement of project time and cost objectives.
4. *Financial implications:* They contain sales forecast, project budget, capital costs, profitability trend, payback period, net present worth, cash flow forecast, and sources of financing.
5. *Economic viability:* It highlights social implications and cost benefit analysis.
6. Summary of recommendations.

Project investment analysis and appraisal. The feasibility report, if found acceptable, is followed up with an investment appraisal. The purpose of the appraisal is to conduct an objective assessment for making the investment decision. It involves a critical examination of the techno-economic analysis of the feasibility findings, with particular reference to:

* Demand analysis,
* Technical specification feasibility,
* Strength, weakness, opportunity and threat (SWOT) analysis,
* Environment implications,
* Financial analysis, and
* Economic analysis.

Appraisal of the feasibility stage enables a client to:

a. Decide on the project concept, time and costs;
b. Outline the approach needed to take the project;

c. Appoint key persons like construction project managers or project coordinators to act as his representatives; and

d. Nominate specialist associated agencies such as the architect, designer and consultants, as per the requirements.

The process of formulation of needs, collection of information, critical examination of concepts and re-examination of needs, and feasibility of the project may have to be repeated several times over before a project's inception finally takes shape.

Project scope formulation and implementation strategy.   In case the project is financially viable, and the client decides to go ahead and develop the implementation strategy. This strategic plan or charter or work operation order generally includes the following:

- Broad scope of work including WBS, and functional and technical specifications of the work;
- Project objectives;
- Outline execution methodology;
- Preliminary milestone accomplishment;
- Critical resource forecasts;
- Cash flow pattern and sources of funding;
- Outline organisation and responsibility assignment matrix; and
- Potential risks and problem areas.

The project strategic plan or project charter is issued by the client in the form of an executive order or the project operation order. It is supported with the outline plan, policy and procedures, and it is circulated to all the persons concerned with the decision-making and management of the project. This strategic plan forms the basis for the start of the project management process and actions of the project management.

1.5.3   Processes in Construction Project Planning Phase

Processes in project planning phase are as follows:

- Designs and drawings planning;
- Time planning;
- Resource planning;
- Cost planning and budgeting;
- Communications planning;
- Quality assurance planning;
- Organisational planning;
- Construction contracts procurement planning;
- Resources mobilisation planning;
- Site administration and layout planning;
- Workers' safety, health and environment protection plan; and
- Risk response planning.

Planning is the process of developing the project plan. The plan outlines how the project is to be directed to achieve the assigned goals. It specifies a predetermined and committed future course of action, based on discussions and decisions made on the current knowledge and estimation of future trends. Planning aims at formulation of a time-based plan of action for coordinating various activities and resources to achieve specified objectives.

Planning, in its broader perspective, involves advance thinking; as to what is to be done, what are the activities, how it is to be done, when it is to be done, where it is to be done, what is needed to do it, who is to do it and how to ensure that it is done; all of this is channelised to generate and evaluate options for evolving an action plan aimed at achieving the specified goals.

The construction planning process is stimulated through a study of project documents. These documents include, but are not limited to, the available technical and commercial studies and investigations, designs and drawings, estimate of quantities, construction method statements, project planning data, contract documents, site conditions, working regulations, market survey, local resources, project environment and the client's organisation. The planning process takes into account the strengths and weaknesses of the organisation as well as the anticipated opportunities and risks.

Planning the entire project from its inception to completion requires vast coverage, varied skills, and different types of plans. The development of types of plans encountered in a typical construction project is indicated below.

Inception or formulation phase	Client project conceptual plan
Engineering and planning phase	Client project strategic or preliminary plan
Implementation phase	Client and contractor project detailed construction plan

Note. Due to gradual development of scope and stakeholders requirements in complex projects, the above plans are progressively developed /elaborated.

Client project conceptual plan.   Planning by the client begins as soon as he gets the idea about developing a facility to fulfill certain motives. His early thought process gives him the indication of the cost, time and benefit. Only when he is convinced about the soundness of his idea, he decides to go ahead with the feasibility studies.

The feasibility study team, after evaluating the technical feasibility, economic viability and financial implications, conceptualise the overall scope of work and breaks it down into various task groups. It analyses, in outline, the scope of work and assesses the time and costs of accomplishing the project. This outline conceptual plan, developed by the feasibility team during the inception stage, forms the basis for identifying the project direction of work and its milestones.

Client project strategic plan.   Acceptance of the feasibility studies marks the commencement of the strategic or preliminary plan-making process. Its main aim is to provide direction to the client managers and staff employed during the development phase of the project. The project preliminary plan forms the basis for developing the project construction plan. The preliminary plan may include the following:

- A project time schedule and the skeleton network to highlight the work dependencies, project milestones and the expected project completion time;
- The project is designed and preparation schedule is drawn;
- Breaking down of project works into contracts, along with a schedule of contracting activities, including the tender preparation period, tender finalisation period, and the contracted works commencement and completion dates;
- A resources preliminary forecast indicating the phased requirement of men, important materials, plant and machinery;
- Resources procurement system;
- Project organisation and staffing pattern; and
- A preliminary forecast of funds required.

In this planning phase, the project manager, assisted by the chief project planner, performs the key functions. These include, but are not limited to, the following:

1. Participate in the finalisation of design, drawings and specifications so as to formulate construction methodology.
2. Prepare project execution preliminary plan and formulate the schedule for processing various contracts.
3. Advise the client on an early purchase of the items of plant and equipment needing a long lead time for procurement.
4. Evolve the pre-tender construction plan for each tender package.
5. Scrutinise the tender packages, including drawings and specifications, so as to minimise the discrepancies.
6. Conduct the pre-tender briefing to contractors to ensure that the bidders understand the tender documents and the work involved in each tender.
7. Evaluate project costs and compile project budget including preliminary allocations for the various heads of expenditures.
8. Compile a project directive covering the scope of work, work plan, organisation, and the policies and procedures for implementing the project.

Client and contractor detailed construction plan.   The client entrusts the construction of project facilities to the project management team headed by the project manager or the resident engineer. This team may be from the client's own construction agency or from a client-appointed construction management consulting firm or from a suitably organised combination of these. The planning chief, who is a member of the project management team, is entrusted with the task of developing the project construction plan. This plan includes the contracted work plans and the commissioning plan, as applicable. The work programmes are derived from the targets set out in the preliminary project plan.

The project construction plans as well as the contracted work plan follow a systematic approach. Various planning techniques are employed to systematise and transform the mental thought process into the project plans listed above. A plan, prepared well before the commencement of construction

in a project, can be instrumental in formulating directions, coordinating functions, setting targets, forecasting resources, budgeting costs, controlling performance and motivating people.

1.5.4 Processes in Project Construction Phase

Processes relating to project construction are as follows:

- Project site organisation,
- Resource mobilisation,
- Scope quality assurance team development,
- Information distribution, and
- Contract administration.

This phase concerns with coordinating and managing people and other resources to carry out the project plan. In the construction phase, execution and control are concurrent processes.

Construction at the site of the contracted projects is supervised and carried out by two separate agencies. These are: the client team led by the project manager, and the contractor workforce managed by his construction manager. Both teams have the common goal of completing the project in time within the specified costs and quality specifications. However, their roles differ.

At the site, the contractor's construction managers execute their assigned work. They operate to achieve the contractor's objectives, which include optimising profit. Client project manager manages the contractors employed at site with the help of his supervisory team that reports to him for decisions.

It is the client project manager who plays a dominant role. He represents a client and acts as the boss at the site. He manages the contractors employed at site, and the site activities, with the help of his supervisory team that reports to him for decisions. It is he who is accountable to the client for the construction of the project.

The main functions of the construction supervision team are outlined below:

1. Scrutinise the contract documents to ensure that all amendments are incorporated into the drawings, specifications and bill of quantities held at site.
2. Scrutinise the contractor's plan of work, the mobilisation plan, the construction procedures and the quality control measures to ensure that they are in order.
3. Scrutinise the pre-work preparation of work to ensure a smooth start of construction activities.
4. Scrutinise the work programmes to ensure that they are realistic, and monitor their progress regularly.
5. Scrutinise the quality of materials to ensure that they meet the contract specifications and also report any deviations.
6. Scrutinise the geotechnical investigations conducted by the contractor to ensure the adequacy of design parameters.
7. Scrutinise the field work regularly to ensure proper layouts, work conformity as per drawings and specifications, and good standards of workmanship.
8. Scrutinise the safety measures and working conditions to ensure healthy environments and prevention of accidents.

9. Hold review meetings to monitor progress, communicate observations, resolve problems and plan future works.
10. Scrutinise the payment of monthly bills of contractors to ensure correctness.
11. Exercise cost control and cost reduction measures.
12. Maintain project records, monitor the progress and submit management information reports at the predetermined frequency.
13. Report immediately to the project manager all cases amounting to breach of contract, non-adherence to specifications, slow progress and lack of co-operation.
14. Take the project to completion, as per the contract stipulations.

At the site, the contractor's construction manager manages the work execution as well as the resources, and the workforce. He operates to achieve the contractor's objectives, which include administrating contracts, progressing works, monitoring performance optimising profit, maintaining a cooperative and harmonious relationship with the project manager and others engaged in the construction activity at the site.

1.5.5 Processes in Performance Controlling

Various steps of performance controlling processes are as follows:

- Scope change control,
- Resources control,
- Schedule control,
- Cost control,
- Quality control,
- Risk response control, and
- Earned value performance control.

Project plan indicates the path to achieve objectives. During the construction phase, the project control aims to track the progress of work as per the planned schedule and take corrective actions including re-planning, when necessary, to achieve the project objectives. Planning and controlling are inseparable. In fact during the execution stage, it is the planning team that takes over the control function. Project control follows a system concept. Each organisational unit in a project usually referred to as Responsibility Centre, can be viewed as a sub-system. These sub-systems are highly interdependent and interactive. Each sub-system accounts for its performance and reports the deviation between the actual and the planned to the Project Control Centre. This Control Centre, manned by the project monitor, is the heart of the system; it receives the performance data from the responsibility centres and using scientific tools and techniques, transforms this data into information suggesting remedial courses of action for achieving the objectives. This information, when fed at the appropriate levels, results in steering organisational effort towards the attainment of the project objectives.

1.5.6   Processes in Construction Project Closing Phase

Closing phase processes are as follows:

- Maintenance close,
- Administrative close,
- Contract closeout, amd
- Lessons learnt report.

This phase formalises the acceptance of the project work and brings it to an orderly end. After completion by the contractor, it is the project team of the client that hands over the project to the client.

The main focus of the project team in closing the project is to ensure that the project's product meets the stipulated requirements and functions satisfactorily after it is handed over to the client. The team prepares a project manual which may include the project history, the important events, the scope and schedule of work, the salient features of the contract(s) executed, the addresses of the suppliers of materials and equipment, the equipment operational and maintenance manual, the as-built drawings and the final costs. It may also include the problems encountered during execution, the lessons learnt, the minor defects noticed at the time of handing over and post-completion maintenance requirements. In most cases, the contractor responsible for the construction is given a one year maintenance responsibility after completion. This aspect is generally included in the scope of the work of the contract. In addition, the staff and workers necessary for operating and maintaining the facility are trained prior to its taking over and the project is cleared of the remaining unwanted materials. The project team fully safeguards the client's interest before making the final payments.

A properly closed project is an invaluable asset to the organisation and stakeholders who participated in the accomplishment of the project. Project closing is important but often a neglected phase of a project. The various reasons that lead to neglect in the closing phase of a project include insufficient time, extra effort, lack of enthusiasm after completion of the project, etc. In cases, where the project performance is not satisfactory, the project team may have inhibitions about discussing the shortcomings that made it unsuccessful.

❏ 1.6   CONSTRUCTION PROJECT MANAGEMENT PRACTICE

1.6.1   Classic Functions of General Management

The overall aim of the management in an enterprise is to create within the enterprise an environment, which will facilitate the accomplishment of its objectives. In doing this, management has to perform certain functions. Although the development of a theory and science of management suffers from disagreement among scholars and managers, a general pattern of functions which management has to perform, has emerged. Traditionally, management functions are grouped under

six headings, namely: forecasting, planning, organising, staffing, directing and controlling, and common to all these functions is the function of coordination and communication. These are outlined in **Table 1.11**.

1.6.2 What is Project Management?

Project management is the art and science of converting the client's vision into reality by working efficiently, effectively and safely. The British Standard BS 6079: 2000 defines project management as the planning, monitoring and controlling of all aspects of a project and the motivation of all those involved in it to achieve the projective objectives on time and to the specified cost, quality and performance. Project management, according to ISO 10006: 1997(E), includes: the planning, organising, monitoring and controlling of all aspects of the project in a continuous process to achieve its objectives. Project Management Institute of the USA describes project management as the application of knowledge, skills, tools and techniques to project activities in order to meet the project requirements.

In the construction context, project management is the art and science of managing all aspects of the project to achieve the project mission objectives, within the specified time, budgeted cost and predefined quality specifications; working efficiently and effectively in the changing project environments with due regard to construction workers' safety and health.

1.6.3 Why Project Management?

Both general management and project management aim to achieve the assigned goal by managing the environment, people and resources. The management principles of planning, organising, staffing, directing, motivating, monitoring, communicating, controlling and decision-making apply equally in the traditional functional type management as well as in the project management, but their management philosophy varies considerably. The risks, uncertainties and complexities make construction project management a relatively difficult and complex process.

Management of construction projects differs from the management of other on-going steady state business enterprises like manufacturing and trading in many ways. The salient features of project management and the management of an industrial enterprise are as follows:

1. The project mission is unique. No two projects are alike. The type of work at each site differs, unlike in industry where a factory manufactures the same type of product repeatedly.
2. Projects are transient in nature. Unlike the on-going steady state enterprises, a project comes to an end after its mission is fulfilled.
3. Projects consist of a variety of specialised works and need a wide range of tradesmen, who are casual employees. Since the projects have a short life, workers move from job to job like nomads, whereas the stable industrial enterprises have more or less permanent employees.
4. Project sites are in open remote areas and are prone to weather changes, whereas industrial setups are housed in a permanent accommodation with friendly working conditions.

Table 1.11

General Management Functions

Planning. It involves deciding in advance what is to be done, how and in what order it is to be done in order to achieve the objectives. Planning aims at deciding upon the future course of action. A plan shows the committed course of action. Schedule depicts when and in what sequence the planned activities are to be carried and puts the plan on a calendar date scale. In brief, planning and scheduling involves the following:

- Crystallising objectives;

- Collecting and synthesising information;

- Developing alternative courses of action within the specified constraints;

- Comparing alternatives in terms of objectives, feasibility and consequences;

- Selecting and scheduling the optimum course of action; and

- Establishing policies, procedures, methods, schedules, programmes, systems, standards and budgets for accomplishing project objectives.

Organising. It is the process of establishing a structural relationship among functions of people, so as to streamline the achievement of assigned objectives. Organising involves the following main tasks:

- Dividing the work into component activities;

- Designing job structures;

- Defining performance targets and responsibilities;

- Allocating resources;

- Delegating authority commensurate with responsibility; and

- Establishing structural relationship to secure coordination.

Staffing and provisioning resources. It implies managing and keeping the positions created by the organisation structure manned and providing them the right quality resources at the right time. These resources include people, materials, machinery and money. The connected management tasks include the following:

- Preparing resource procurement schedules;

- Developing specifications for required resources;

- Deciding appropriate sources of procurement;

- Budgeting resources and arranging approvals and purchases;

- Preventing wastage during resource holding at site; and

- Supplying on time the required quality and quantity of resources.

Directing or leading. It involves influencing people so as to enable them to contribute to organisational goals efficiently and effectively. Direction implies the following tasks:

- Providing effective leadership;

- Motivating the participant's behaviour;

- Communicating instructions and orders; and

- Providing a suitable climate for subordinates' development.

Controlling.   It involves monitoring of the performance and applying corrective measures in case of deviations from the plan. The process of control can be sub-divided into the following stages:

- Specifying the factors to be controlled;
- Stating the methods of measuring control factors;
- Evolving systems for generating performance data;
- Monitoring data received and formulating corrective options;
- Applying corrective measures to put a plan on the scheduled path; and
- Replanning, when necessary.

  Coordination and communication. These are essentials in each management function.

5. Project works are carried out at places that are far away from the corporate head offices, unlike the industrial management, which is generally located at the place of work.
6. Project work, especially in high-rise buildings, involves operations at heights, making the accident rate manifold higher than in industrial factories.
7. Construction projects operate under risk and uncertain conditions as compared to well-defined industrial processes.
8. The predetermined and specified start and completion dates of projects do not leave any time flexibility, especially when projects are to be executed speedily under relatively risk prone complex situations and resource constraints.
9. Time delays in between the project execution can alter the schedule of subsequent activities. Project delays attract heavy penalties. Cost on account of time delays, unless properly controlled, can increase exponentially instead of marginally as in case of other on-going enterprises.
10. Quality at each stage of project work is inspected. Construction quality judgment lies with the inspector of works in contrast to the measurement of tolerances of an industrial product. Further acceptance of any work does not absolve the builder of defects appearing later on. In such situations, generally the entire completed affected work gets rejected, unlike with the one product rejection in the manufacturing process.
11. Project tasks are generally non-routine. They are to be executed speedily. This hardly leaves any time for training or learning process. Accordingly projects employ experienced staff with proven skills. Comparatively, it is difficult to get state-of-the-art experienced project operations and management personnel as compared to the on-going enterprises.
12. Since projects are generally handled by various associates/organisations/companies, they re sult in social, organisational, technical and economic interactions. Unlike in on-going co ncerns, any adverse effects on one project leads to repercussions on other interdependent projects.
13. Most projects by nature contain several interrelated sub-systems. Integration of activities of several sub-systems requires coordination and needs information for making decisions. Information extraction for making decisions at various levels of management is relatively complex under dynamic complex project environments as compared to the on-going stable enterprises.

With the accelerated changes in the environment, management of multi-discipline, multi-dimensional, multi-location, multi-national tasks need project management philosophy different from the traditional functional organisational structures of the ongoing industrial establishments.

1.6.4 The Emerging Project Management Philosophy

Historical development. In construction, the concept of projectising tasks is not new. It dates back to the times when the caveman started building his dwellings, but the modern project management is a young emerging new management practice.

The project management discipline originated with the development of CPM/PERT network— the analytical techniques of the early sixties, when the volume and complexity of tasks increased, especially in construction, aerospace, and defence projects. These network techniques were primarily developed for controlling time and cost of the complex projects. During the seventies, with the custom arose a demand for quality in products, new project management emerged with a focus also on quality improvement. The 1980s witnessed total quality management revolution and thus project management got identified with management of three constraints, i.e. time, cost and product quality.

The rapid growth in the Information technology made PC, a home device. The internet brought in the information revolution. Bill Gates called eighties as the decade of quality, nineties about engineering new business processes and in the 2000s, he says, the nature of business and the lifestyle of the consumers will change because of the flow of digital information. In the new millennium, the product life cycles are becoming shorter. Engineering/technology appears to be doubling over five years or less. Computer technology is doubling every two years.

Emerging trends. Modern projects differ from the past practices. The fast changing environment of the present era imposes numerous time, cost, financial, legal, ethical, environmental, and logistic constraints. Construction projects contain numerous interdependent and interrelated activities. They interact technically, economically and socially within the environment as well as with other organisations, structures and systems. These projects employ voluminous resources. The customers are demanding new products at cheaper rates with shorter product development time; whereas the development processes are becoming larger in scale and complexity. The terrorist outfits have added a new dimension to the uncertain environments. All these have added new dimensions in the form of risky environments, financial constraints, changing technology implications and organisational structures (see **Figure 1.11**).

These new developments demand the control of changes at all times and from all causes during the implementation. With the accelerated rate of change, management of multi-discipline, multi-dimensional, multi-national tasks need management philosophy which is different from the traditional functional organisational structures. Such new trends are moving the corporates to projectise their operations. This has led to the emergence of a management philosophy of management-by-projects. However, obstacles to project management are the problems relating to the conflicts, client interference, unstable environment, technology changes and the scarcity of the competent project managers.

Figure 1.11

Total Construction Project Management Model
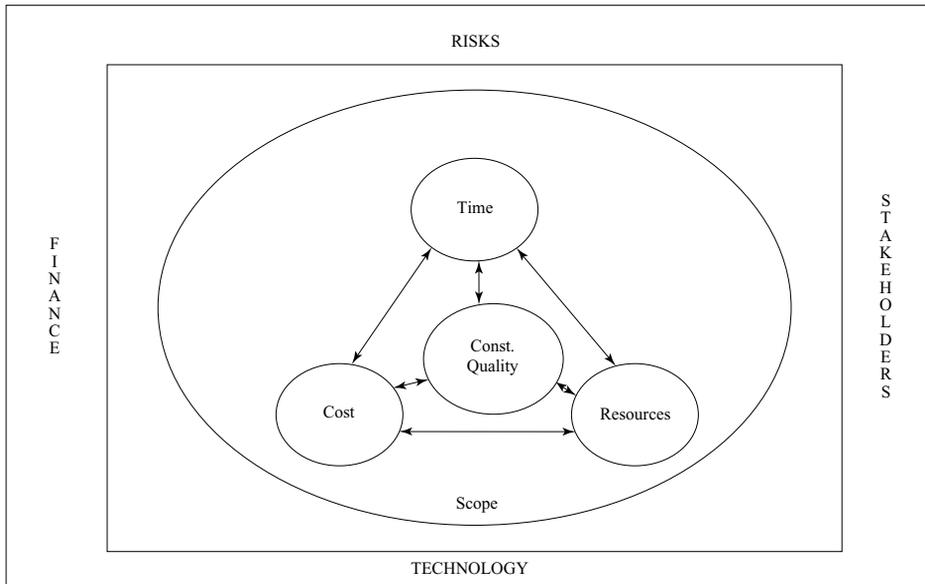
❑ 1.7 CONSTRUCTION PROJECT ORGANISATION

1.7.1 Project Organisation Attributes

A project is organised to achieve its mission by pre-determined objectives. Its organisation is temporary. Project organisation is conceived during the project initiation stage and it comes into existence prior to the start of the planning stage. It grows gradually. It undergoes changes in various stages of the project life cycle to meet project needs. Towards the end, it runs down and ceases after completion of the project. Its special attributes include its innovation and capacity to overcome problems as they arise. It is staffed with experienced people to respond speedily to changing situations and to speed up decision making. The responsibility of accomplishment is entrusted to a single person—the project manager, who acts as a single point of accountability. The success of a project to a great extent hinges on the efficient and effective management of the physical resources of manpower, material and machinery.

1.7.2 Organisation for Construction Project Management

Organisation enables a group of people working together with divided tasks and responsibilities, to co-ordinate their activities harmoniously in order to achieve a common goal. The fast-changing technology and the demand for cheaper, better and faster delivery of new products, have led to new thinking towards restructuring, downsising and empowerment of the organisations. With the accelerated rate of change in environment, management of multi-discipline, multi-dimensional, multi-

location, multi-national project tasks need organisation different from the traditional, functional organisational structures. Construction corporates have high stakes in the projects undertaken by them. Delay in the projects invites high penalty, cost overruns, and can even mar the very existence of the firm. In general, large construction corporates create special organisations to handle a pro ject. Project organisation is a result of this new evolutionary process.

Project-based organisation use various organisation forms in projects. Depending upon the nature of the project and the corporate policy, the project management organisation forms vary from centralised functional form on the one extreme to a highly decentralised pure product/project form on the other end; there are many matrix-type organisational forms in between these two extremes. The typical forms of project organisations are tabulated below:

Construction Project Management Organisation Forms

Org. Forms /Project Characteristics	Functional Organisation	Matrix Organisation			Projectised Organisation
		Weak Matrix	Balanced Matrix	Strong Matrix	
Project Manager's Authority	Little or None	Limited	Moderate	Moderate to High	High to Almost Total
Performing Organisation's Personnel Assigned Full-time	Virtually None	Limited	Moderate	60%–85%	85%–100%
Project Manager's Role	Coordinator	Expeditor	Mixer	Collaborative	Collaborative
Budget Management Responsibility	Functional Manager	Functional Manager	Project Officer	Project Manager/ Program Manager	Project Manager
Project Management Administrative Staff	Part-time	Part-time	Part-time	Full-time	Full-time

Functional Organisational Form.   Traditionally a construction corporate is organised on centralised functional forms. Its departments are arranged by functions such as marketing, engineering, production, contract, resource procurement, finance, HRD; each headed by a director/specialist manager. Its centre of power and co-ordination is concentrated at the top with the chief executive. The classic principles of organisation and their limitations considered while designing Functional Organisation are given in **Chapter 7**.

Functional organisational form has its advantages and limitations. Traditional functional organisational form provides stable environments, unified command, better technical control, quick reaction capability, economical utilisation of specialists, excellent co-ordination within functions, and requires fewer inter-personal skills. The main limitations of traditional form are that no one person is accountable for achieving the organisational goals, the communication is poor across functional departments, co-ordination is difficult, response time to external changes is slow and it fails to encourage innovation and creativity.

Pure Projectised or Product Form.   Pure project/product organisation is a division of the corporate organisation, but it operates independent of the parent organisation. It has dedicated multi-discipline resources assigned to accomplish the specified product goals. A product organisation is headed by a programme director/manager, who maintains complete line authority over the product. The main advantage of product organisation is that one person is accountable for achieving the organisational goals, there are strong communication channels, coordination is easy, response time to external changes is less and it encourages innovation and creativity. The main limitations are that it is temporary.

Matrix Form.   Depending upon the nature of the project and the corporate policy, the project management organisation matrix pattern can vary from a highly centralised functional organisation to a dedicated project team with fully decentralised authority. The matrix organisation of project management lies in-between the two extreme organisational concepts, i.e. Functional and Pure Project Forms. Project Matrix Organisation is a subset of the construction corporate organisation. A typical matrix structure of project focused construction corporate organisation is shown in **Figure 1.12**.

The matrix structure is viewed as a temporary organisation having human and non-human resources with reduced vertical hierarchy so as to respond speedily in a changing complex situation for achieving the specified performance objectives. In a weak 'matrix' organisation, the project manager's role is that of a co-ordinator or an expeditor; whereas in a strong 'matrix' organisation, the project manager has a collaborative role. In the projectised organisation, with a weak matrix, authority for decision making and direction rests with the project manager; whereas in a strong 'matrix' structure, information sharing is mandatory and decision making rests with the task-oriented teams.

In the matrix form the managers in a project team are its key personnel. They are drawn from their parent departments and are specialists in their field. They are charged with the responsibility of their respective areas of activity. In this way, communication and coordination between top management and project management is improved.

Following are the characteristics of the matrix structure:

a. It has a single project manager accountable for the whole project. The project management, working as a team, performs the basic management functions of planning, organising, staffing, directing, controlling and coordinating the project work.

b. All managers owe their allegiance to the project manager, and not to their parent departmental heads.

c. Personal commitment to objectives is the key note of matrix organisation. It provides a climate for motivation, effectiveness and personal development.

d. The specialist staff is employed effectively. The matrix organisation balances their conflicting objectives by reducing the communication gap.

e. The top management is freed from making routine decisions, as the decision-making machinery forms an integral part of the matrix structure.

f. It provides enough flexibility to meet uncertain and changing situations by establishing a

Figure 1.12

Construction Project Management: Matrix Organisation

Construction Company Corporate Office

Projects Director — Other Functions

Management Services | Planning Management | Structural Engineering | Elec & Mech Engineering | Contracts Administration

Functional Representatives from Parent Departments

Project A: Project Manager | Planning Manager | Technical Manager | Services Manager | Contract Manager

Project B: Project Manager | Planning Manager | Technical Manager | Services Manager | Contract Manager

Project C: Project Manager | Planning Manager | Technical Manager | Services Manager | Contract Manager

project planning and control system at site to monitor the input flow of resources and the performance output.

However, if not properly conceived and directed, the matrix organisation can result in increased conflicts, lack of coordination, low productivity, and enhanced costs.

In the fast changing environments and technology, each project organisation will have to be tailored to meet the requirement by adopting the correct 'martrix' which will put 'authority', 'responsibility' and 'accountability' in the right perspective. A project organisation can be responsive to changes in environment if it is provided with inbuilt flexibility and the necessary delegation of power to the project manager.

The project organisation will need to be tailored to the requirements. Undoubtedly the principles of organisational theories (refer to **Chapter 7**) have universal application, but they need to be modified to suit the situation. The emphasis on project organisation varies somewhat from standard organisations and demands the following:

- Decentralisation of power and authority to the project manager;
- Equal emphasis on the human and professional skills of the project managers and the supervisory staff; and
- Proper integration of the task-oriented teams, through a well-conceived communication channel, enabling good interaction, both vertically and horizontally.

The key to providing an effective project organisation is to strike the right interface between itself and the parent corporate organisation by adopting the correct matrix, which will put authority, responsibility and accountability in the right perspective. An organisation can be responsive to change in the environment, if it is provided with an inbuilt flexibility and the necessary delegation of power to the project manager.

1.7.3 Project Management Team

The project team includes project manager, the heads of departments, and the project key personnel. They are drawn from their parent departments and are specialists in their fields. They are entrusted with the responsibility of their respective areas of activity. In this way, communication and coordination between top management and project management is improved. The composition of the project team varies from project to project but it is always headed by the project manager.

Traditionally the project management organisation is generally categorised into line and staff. The line personnel are those who directly contribute to performing work that produces deliverables; the members of staffs are personnel who support the work indirectly and advisors are the specialists/consultants who advise the management on issues such as legal, financial, environmental and political matters. To quote an example, 2000 Housing Units Project Organisation is outlined in **Exhibit 1.1**. The designing of project site operating units, estimating manpower requirements, scheduling construction site workers and designing workers' financial incentive schemes are covered in details in **Chapter 7**.

The project management team is led by a project manager, who is appointed by the client and acts on his behalf. He coordinates and communicates with all the agencies engaged in project work. In particular, he is accountable for planning, mobilising, motivating, directing, coordinating and controlling all the activities at the project site, which are necessary for achieving the project objectives of time, cost and quality. Loosely, the site-in-charge of a major contractor is also referred as contractor's Project Manager.

Following are the roles played by project team:

1. The project management team performs the assigned management functions of planning, organising, staffing, directing, controlling and coordinating the project work.
2. All managers owe their allegiance to the project manager, and not to their parent departmental heads.

Exhibit 1.1

Project Organisation

Project Organisation
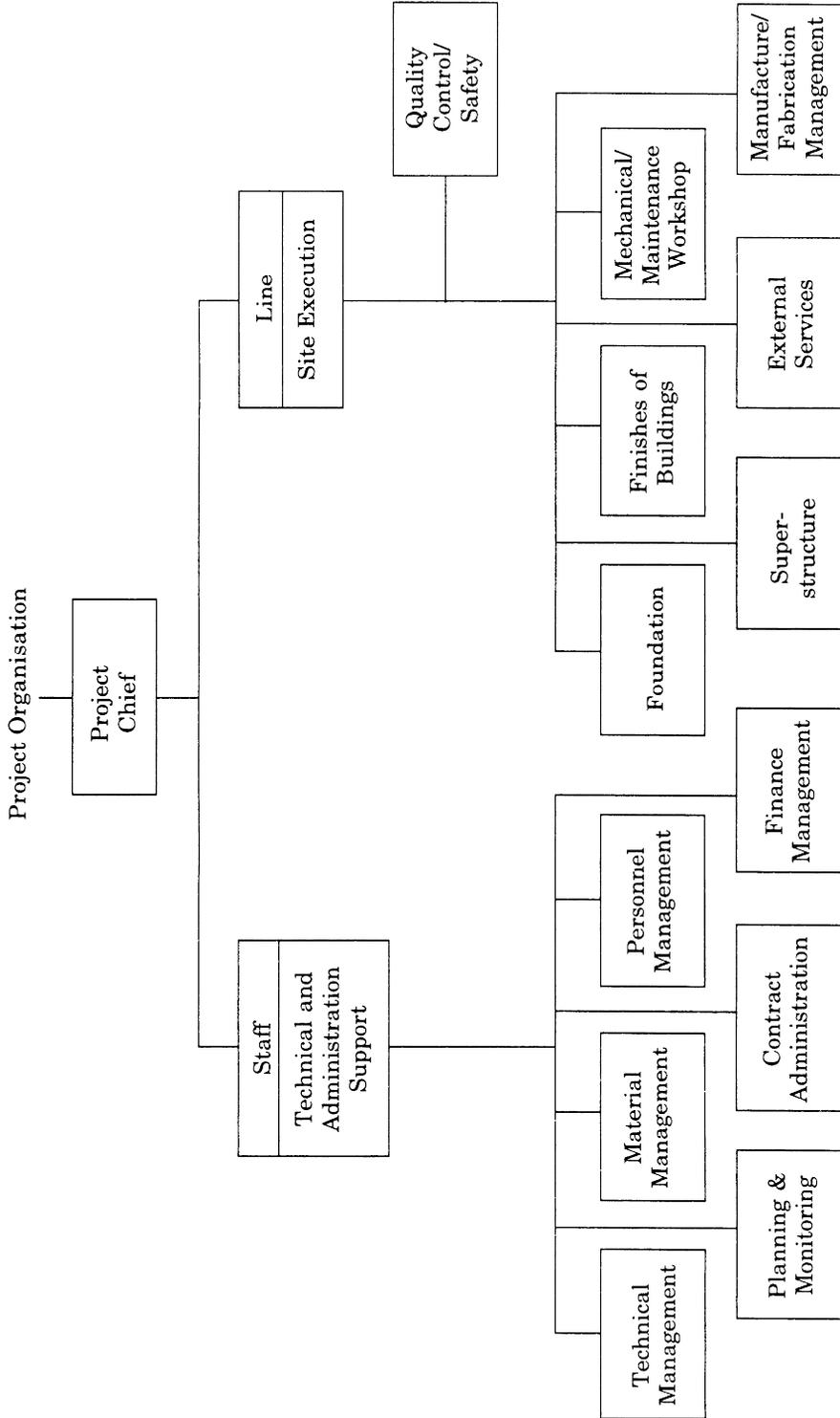
3. Personal commitment to objectives is the key note of a matrix organisation. It provides a climate for motivation, effectiveness and personal development.
4. The specialist staff is employed effectively. The matrix organisation balances its conflicting objectives by reducing the communication gap.
5. The top management is freed from making routine decisions, as the decision-making machinery forms an integral part of the matrix structure.
6. It provides enough flexibility to meet uncertain and changing situations by establishing a project planning and control system at site to monitor the input flow of resources and the performance output.

The achievement of the project objectives is closely linked with the skill, effectiveness and efficiency of the project management team, and how it is organised for conducting its operations. This team consists of the functional heads or the body of managers in a project.

The size of the project management team depends upon the nature and scope of the project work. In medium and large-size projects, it may include specialists to manage: construction planning, architecture and engineering, tendering and contract administration, value analysis and quality assurance, materials and equipment handling, and finance and personnel administration.

Depending upon the size and nature of the project, the managers in the project team are entrusted with the responsibility to accomplish project tasks. A large complex project may have a manager in-charge of each specialised task, whereas in smaller and less complex projects, only few managers can look into all the tasks. The various ways in which the duties of a manager can be combined with those of the project manager in a small project are:

- Project manager/construction superintendent/planning and controlling manager, can be a sin tvvgle individual;
- Project manager/resources procurement manager/construction superintendent, can be a single individual; and
- Project manager/planning and controlling manager/contract manager, can be the same person.

Note: The competent project team members, if not properly managed, do not necessarily produce good performance; but a poorly managed team even with competent people, invariably results in poor performance.

❑ 1.8 ROLE AND FUNCTIONS OF CONSTRUCTION PROJECT MANAGER

1.8.1 Role of Construction Project Manager

The project manager is the kingpin around whom the whole project organisation revolves. He assumes total responsibility and accountability for the success or failure of the project. His functions may vary with the nature of the project and organisational setup, but his roles which reflect the be-

haviour patterns are generally similar in almost all types of projects. Ten related roles of the project manager are outlined below:

a. **Governance role.** The project manager is the legal and social head of the project. He is the single focal point for making decisions, ceremonial functions and symbolic duties.

b. **Leadership role.** As a leader, the project manager directs the inter-functional efforts through a complex web of relationships created in the project organisation by building a performance-motivated team of skilled and experienced people who collectively face the challenges posed by the environment. In crisis-prone environments, effective leadership is an essential requirement for success and accomplishment of the project mission, but it does assume far greater significance in Construction Projects.

c. **Liaison role.** The project manager maintains contacts outside the organisation, deals with those activities which may involve correspondence and contact with the concerned government and non-government officials, contract vendors, professionals, and top persons of the construction industry.

d. **Monitoring role.** The project manager's focus is on the planned baseline for performing tasks, and implementing time, cost and quality planning and monitoring system. He motivates the project team to provide timely results on project performance objectives.

e. **Disseminator's role.** The project manager transmits the relevant information received from external sources and internal systems to the concerned people in the work place. This information may be written or verbal, formal or informal.

f. **Spokesperson's role.** The project manager acts as the sole representative through whom all communications with the client or other external parties are conducted outside the project site.

g. **Entrepreneur's role.** The project manager seeks and identifies opportunities to promote improvements and needed changes.

h. **Disturbance handling role.** The project manager maintains organisational harmony by resolving conflicts and diagnosing organisational behaviour on time. He applies corrective action when the organisation faces important unexpected disturbances.

i. **Resources allocation role.** The project manager takes responsibility for allocating/altering the project resources and makes any changes which are necessary to ensure the availability of adequate resources on time. This role also calls for developing and monitoring budgets and predicting future resource needs.

j. **Negotiator's role.** The project manager negotiates important conflicting issues and business related matters, both inside and outside of the project environment. He represents the organisation on major negotiations.

1.8.2 Project Governance Functions

Project manager is accountable for all governance functions. These functions describe the activities performed by the project manager and his project team. Project manager assisted by his staff may be directly responsible for the executive functions whereas he may be assisted by the expert manag-

ers in specialised functions relating to contract, finance and legal affairs. These functions may vary with the nature of the project and organisational setup, but these are generally similar in most of the construction projects. The executive functions include envisioning the task ahead, enabling the individuals to perform the task systematically and efficiently, setting targets and monitoring performance, providing resources support, implementing financial incentive schemes, communicating feedback, motivating the workforce, building the line-supervisor team, creating a safe working environment, abiding by professional ethics and it is the leadership that makes all the difference. The functions that specifically need attention of project manager include but are not limited to the following:

- Workers' safety and health. Managing worker safety and healthy work environment come first always;
- Technical management and functionality. Manage the facility production so that it must serve the purpose for which the project is undertaken;
- Work scope. It has several components and these have to be coordinated to meet functional requirements. Minimises changes in scope of work;
- Product quality. Manage the quality of work to eliminate the rework;
- Project organisation. Organisation is what people skills are. HRD is a continuous process;
- Resources control. Keep a watch on planned procurement and productivity;
- Cost management. It is a delight to manage production within the budgeted cost;
- Completion time management. Project completion within the time is the essence of the project;
- Contract management. Manage and administer contracts effectively;
- Risks and environment management. Management of risks is the key to success;
- Leadership, HRD and social activities; and
- Professional ethics.

1.8.3   Leadership Makes All the Difference

What is leadership?   In layman's language, a leader is the person who leads or guides a group of people and leadership is the ability to lead. The leader leads by influencing people. Mankind has produced great leaders who influenced the destinies of organisations, societies and nations in various fields.

Leadership is difficult to define precisely. There are as many definitions of leadership as there are persons who have attempted to define leadership. In the book titled *Leaders: The Strategies of Taking Charge*, Nanus and Bennis have reported "some 350 definitions of leadership that the studies have generated in the last 30 years." On the one hand are those who say that "A leader is one who succeeds in getting others to follow." However, there are those who emphasise that "Leadership is the initiation of acts which result in a consistent pattern or group interaction directed

towards the solution of mutual problems." Some definitions are person-oriented and the others are performance-oriented. However, a common thread that runs through almost all the definitions is that "leadership is the art of influencing the work groups to achieve the mission and leadership is situational and dynamic process".

Figure. 3.4

Leadership as a Dynamic Process
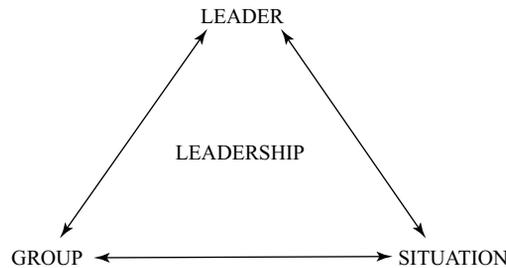
Role of the project leader. It is the leader who harnesses all the potential of an organisation and its people and steers it towards success. In project environment, the project leader plays the following role:

- Fills in the gaps in the incompleteness or imperfection of organisational design it is impossible to design an organisation that will provide for all contingencies;
- Marshals resources to meet continually changing environmental conditions;
- Effects changes in structure and policy as the project organisation grows;
- Creates conditions that give its members a feeling of identification with the organisation and pride in belonging to it; and
- Deals with the human issues that continually arise.

Key functions of the leader. Managing processes in a project by optimising resources is not enough. It is the leadership that creates a vision, integrates the tasks, teams and people, gives a direction, motivates individuals and work groups, communicates effectively to influence organisational behaviour and ensures customer satisfaction. Managing processes in a project by optimising resources is not enough. The tasks of a leader are multi-directional. In a crisis-prone environment leadership skills are needed to envision the project, energize the human resources and enable the workforce to achieve the mission. The following are the key functions, which a modern leader must be able to perform.

1. *Envision the project processes that integrate tasks, teams and people with a view to leading the organisation towards the defined goals. This includes:*

- Looking upwards: Managing the sponsor in order to achieve organisational commitments;
- Looking outwards: Managing the client, end-user, and external stakeholders (including suppliers and subcontractors) to ensure that the project meets their expectations;
- Looking backwards: Monitoring progress with appropriate control systems, to ensure that the project meets its targets and that the team learns from its mistakes;
- Looking inwards: Managing himself, by reviewing his own performance to ensure that his leadership of the team is a positive contribution to the project;
- Looking forward: Planning in order to ensure that the team sets realistic targets and obtains appropriate resources to achieve those targets; and
- Looking downwards: Managing the team in order to maximise their performance both as individuals and collectively.

2. *Energise the human resources by developing and motivating individuals and work groups to work enthusiastically. This involves:*

- Developing the people skills to their full potential and careers;
- Organising and networking project teams;
- Committing the organisation to accomplish project objectives; and
- Motivating individuals and teams into committing to do their best.

3. *Enable the individuals and the work groups to perform enthusiastically to their full potential. This involves:*

- Communicating effectively to influence the organisational behaviour and ensure customer satisfaction;
- Coaching individuals and teams rather than directing them;
- Monitoring work processes to accomplish objectives;
- Managing changes and conflicts; and
- Delivering products and services that satisfy the customer.

What makes an effective leader? Effective leadership is an essential requirement for the successful accomplishment of all management activities, but it does assume far greater significance in project management as project management differs from functional management in many ways. A projects mission is unique, its organisation is temporary, it is transient in nature and project costs on account of time delays can increase exponentially. There are expectations of stakeholders, task requirements, peer behaviour, aspirations of subordinates, organisational policies and changing environments. The in-built difficulties, uncertainties and risks pose never-ending problems and create frequent crises. Furthermore, the various projects in a company are generally interdependent and any adverse effects in one project can have repercussions on the others. All these characteristics place a heavy demand on the leadership skills of the project manager.

There are several complex elements that determine leadership effectiveness under project environments. Literature on leadership is full of numerous theories, which attempt to clarify exactly

what it is that makes an effective leader. It is generally agreed that leadership is situational. Taking a broader view, the major variables that affect the leadership effectiveness can be broadly grouped under the following heads:

• Competency characteristics of the leader-special qualities such as intelligence, technical skills, human skills, attitudes and traits;
• Behaviour style and emotional stability; and
• Culture of the organisation and influence of the environment.

However, what is it that causes leadership failure? Some of the studies bring out the fact that the failure of a leader is usually due to a cluster of reasons and not just one reason. The common reasons found for leadership derailment are:

• Rigid, abrasive and arrogant style of functioning;
• Over ambition and power politics;
• Failure to handle performance problems on time;
• Unwillingness to delegate responsibilities and over-managing specialist technical tasks;
• Inability to build a work team;
• Overdependence on superiors and mentors; and
• Betrayal of trust and failure to meet commitments.

Good management is essential for the successful accomplishment of all projects, but it demands a bias towards strong leadership at various levels of the organisation. It is the sheer dynamism of the project leader manager, which greatly influences the supervisors and the workforce, driving them willfully towards the common goal of completion of the work within the specified objectives. It is the leadership that makes all the difference to the success or failure of a project.

❑ 1.9 MAIN CAUSES OF PROJECT FAILURE

1.9.1 India's Public Sector Project Performance

It is not uncommon to see a project failing to achieve its mission of creating a facility within the specified cost and time. Hardly few projects get completed in time and within original costs. The status of performance of India's Public Sector Projects generally follows the adverse time and cost overrun trend since the year 2000.

According to the annual year 2007 report of the Ministry of Programme Implementation of India, out of 866 projects each costing over Rs. 20 crores, the status was as follows:

• 56% had cost overruns (totalling 20% cost); and
• 49% faced a time overrun from 1 to 196 months.

Cost Performance of Central Sectors Project of the Government of India, as reported in October 2007 is shown in **Table 1.12**.

Table 1.12

Performance of Central Sector Projects in India

Project Time & Cost Overruns	
Projects (Rs. 20 crore and above)	No. 866
Expenditure till Dec. 2006	Rs. 138905 crore
No. of Delayed Projects	No. 297
Time overrun	1–196 (months)
Cost overrun	Rs. 24389 Crore
Anticipated total cost	Rs. 375888 Crore

Source: Times of India, 29th October 2007.

According to the annual report of the Ministry of Programme Implementation of India, published in *Times of India,* August 2, 2009, about 50% of the 925 project sanctioned by Central Government are running behind schedule. In January 2013, the time overrun status of 572 Central Sector Projects is more than 50% and cost overrun is of the order of Rs. 1.42 lakh crores. Its present status can be viewed in Ministry of Statistics and Programme Implementation website: http://mospi.nic.in/Mospi_New/site/home.aspx.

1.9.2 Some Other Research Findings Highlighting Causes for Project Failure

Kumar Neeraj Jha (2011) studied the project failure attributes resulting in adverse schedule performance, cost performance, quality performance and contractual dispute occurrence and developed 22 attributes resulting in project failure. Out of these, he highlighted the following critical failure causes of adverse schedule, cost, quality and contract performance. These are as under:

- Poor human resources management and labour problems;
- Negative attitude of PM and project participants;
- Conflict between PM and other outside agencies and top management;
- Inadequate Project formulation in the beginning; and
- Holding key decisions in abeyance.

1.9.3 Summarising Major Causes of Project Time and Cost Overruns

Studies reveal that the main controllable causes of the projects time and cost overruns include, but are not limited to, the following:

Project formulation, planning and contract administration failures.   These include:

1. *Inadequate project formulation*. Poor field investigation, inadequate project information, bad cost estimates, lack of experience, inadequate project formulation and feasibility analyses,

poor project appraisal leading to incorrect investment decisions.

2. *Poor planning for implementation.* Inadequate time plan, inadequate resource plan, inadequate equipment supply plan, inter-linking not anticipated, poor organisation, poor cost planning.

3. *Lack of proper contract planning and management.* Improper pre-contract actions, poor post award contract management.

4. *Lack of project management knowledge and skills during execution.* Inefficient and ineffective working, delays, changes in scope of work and location, law and order.

Client Inaccurate budget cost estimate.   Client or the owner estimates, depending upon the purpose, can be categorised into the project proposal indicative cost estimate, preliminary estimate for budgeting costs, detail estimate for controlling costs, definitive estimate to assess cost-at-completion and the final closure cost estimate. The types of estimates, their nomenclature and the methods of estimation vary considerably. Client cost estimation is a continuous process and its final cost is known when the project is near to completion.

Contractors' unrealistic tendered cost estimate.   On receipt of work tenders from the client's consultants, the contractor prepares his detailed estimates within the specified tendering period. Despite the well-established methodology for project estimation, the contractor construction contract estimate still remains a risky proposition. Unlike other industries where the sale price of the product is determined after its manufacture, in construction, generally the works are priced before they are produced. This estimation of costs at the tender stage adds to the business risk of the contractors. A construction contractor always gambles when he bids for a contract. A bid on the higher side (of what he considers reasonable) may mean an opportunity missed for new business, whereas a quotation on the lower side may imply less profits, or possibly a loss or, in some cases, even the contractor's bankruptcy. When the contractor wins a bid for quoting the lowest, his fellow bidders may question his judgment. Studies reveal that the failure rate of the construction contractors is one of the highest among the various types of businesses. A construction contract based on inaccurate cost estimates is bound to fail unless its performance objectives are revised and/or additional funds inducted.

Management failure.   A project environment comprises various interrelated constituents such as resources, tasks, and technology along with the people working against time under stress and strain, and all of these combine together to achieve the common project objectives. The problems of management are so complex that they defy simple solutions. Some of these are beyond the management's control but some can be avoided. The following causes of project failure can be attributed to management failure.

a.   **Work policy failure.** It is due to unclear objectives and targets, unworkable plans, top management's failure to back up the plans, failure to identify critical items, lack of understanding of operating procedures and policy directions, too many change orders, reluctance to take timely decisions, and ignorance of appropriate planning tools and techniques.

b. **Organisational failure.** It is due to incorrect organisational structures resulting in inadequate funding, confusion of responsibility, inadequate delegation of authority at various levels, higher management interference, lack of stress on accountability, and a tendency of people to escape responsibility by passing on the buck.

c. **Human resource failure.** It can be due to an improper choice of the project manager, inexperienced staff, and failure to procure and positioning of skilled manpower as per the planned schedules.

d. **Directional failure.** It can be attributed to a lack of team spirit, internal conflicts, poor human resource management, and labour strikes.

e. **Controlling failure.** It is due to unclear targets, inadequate information flow, incompetency in adopting appropriate monitoring techniques, and an absence of timely corrective measures.

f. **Coordination failure.** It can be attributed to a breakdown of communication at various levels, lack of day-to-day decisions to fill procedural gaps, and an absence of cooperation and esprit de corps.

g. **Procurement failures.** They may be due to faulty procurement of machinery and materials, bad workmanship, poor performance of sub-contractors, accidents, unforeseen bad weather, and a failure to adapt to the local conditions.

h. **Unpredictable causes.** Failures can be due to unforeseen natural calamities like earthquakes, floods and natural disasters. Failures can also result from deliberate attempts made by manipulators during the feasibility stage by incorporating inaccurate time and cost estimates with a view to secure business or start a project. The unpredictable causes need risk management skills.

Systematic planning, scheduling and controlling of projects can go a long way in preventing project collapse due to management failure. The Planning, Scheduling and Controlling methodology employed for managing scope, time, resources, costs and risks are loosely called Project Management Techniques.

❑ 1.10   IMPORTANCE OF INTEGRATED PLANNING, SCHEDULING AND CONTROLLING OF CONSTRUCTION PROJECTS

1.10.1   Planning Benefits

Planning is the process of formulating of a time-based plan of action for coordinating various activities and resources to achieve specified objectives. Planning, in simple words is the process of developing a project plan. The project plan shows how the project is to be directed to achieve the assigned goals. It specifies a pre-determined and a committed future course of action, based on discussions and decisions made on the available knowledge of future trends. "Whatever mode of construction is taken by the client or contractor, sufficient time should be given for construction planning prior to starting of construction. Good planning will get the construction sequence right to avoid delays and rework."

The object of planning construction project is to pre-determine how the project objectives will be achieved. Planning precedes all managerial activities and the process combines systematic creative thinking with planning techniques to develop a project plan. The project plan comprises a time plan, resources plan and plan for controlling the project. It also includes schedules of design and drawing preparation, work quantities, progress of work planned resource allocations, budget costs and cash flow estimates.

1. Project plan clearly defines project's scope of work. It breaks down project objectives into clear, identifiable, quantifiable, attainable and verifiable goals, which are assigned to individuals, and responsibility centres for accomplishment.
2. Project plan aids the management in performing its functions efficiently and effectively. It is the spine of the system and at the core of all management activities. It streamlines the project management process and supports the management organisational structure and functioning.
3. Project plan forms the basis of project operations and directions and shows how the project is to be run. It also specifies the committed future course of actions on the basis of current decision made with available knowledge of the future.
4. Project plan identifies critical activities, thus enabling management of project by exceptions.
5. Project plan provides the yardstick for measuring progress and evaluating resource performance—it aids in developing information systems and decision making during the implementation stage. It further simplifies and smoothen communication to enable coordination among all those involved in project management.
6. Project plans provide the basis for coordinating the efforts of clients, consultants, architects, designers, quantity surveyors, specialists, suppliers, contractors and the project staff.
7. A project plan maintains continuity of work, especially when project organisation is temporary and its staffing is transient in nature.
8. Project plan has built in flexibility in the form of floats to navigate changes in the planned path for meeting fast changing environments.
9. Project plan creates a healthy environment. It promotes unity of purpose among functional diversities to make people time and cost conscious. It commits individuals to tasks and motivates them to achieve challenging targets.

Therefore, a well-conceived project plan, developed before the commencement of project execution stage, can go a long way to prevent a project collapse on account of management failures. But a Construction Project Plan, howsoever skillfully devised, cannot make up for bad management.

1.10.2   Scheduling Benefits

Scheduling means putting the plan on a calendar time scale. During the execution stage, monitoring brings out the progress made against the scheduled base line. Work scheduling serves a fivefold purpose:

1. Schedule simplifying a project plan. The bar chart type work schedule provides a simplified version of the work plan which can be easily understood by all concerned with planning, co-ordination, execution and control of projects.
2. Schedule validates time objectives. Work schedule shows the planned sequence of activities, data-wise. It takes into considerations, the reduction in efficiency resulting from climatic effects on resources while putting the plan of work on a calendar basis. A schedule verifies the accomplishment of the tasks on dates imposed for completion of the project and the achievement of milestones.
3. Schedule aids in the optimisation of resources employed. The work schedule is based on economical employment of the resources of men, materials, and machinery. It avoids abrupt changes from time to time.
4. Schedule enables forecasting of input resources and earned value to indicate the pattern of requirement and the financial state of the project in terms of investment, expenditure, output and income.
5. Schedule brings out implications of time and resource constraints.

1.10.3   Control Benefits

Control deals with the formulation and implementation of corrective actions necessary for achieving project objectives. The control system aids the management at various levels to perform its functions efficiently and effectively for achieving the overall project objectives. The illustration given below shows the typical pyramidal management structure with the nature of control exercised at each level.

The benefits, which can be derived at each level of management through an effective control system, are outlined in **Figure 1.13**:

Operational control at supervisory level. It improves productivity by:

- Minimising unproductive man hours;
- Preventing wastage of materials;
- Economising plant and machinery utilization; and
- Reducing activity execution time.

Administrative control at managerial level. It assists in ensuring project organisational efficiency and effectiveness of:

- Updating the work quantities status and determining the balance scope of work;
- Analysing project time status and its implications on project time objectives;
- Evaluating the production cost status and forecasting future trends;
- Calculating income status and forecasting cash inflows;
- Computing budget status and forecasting cash inflows; and
- Computing budget status and analysing the implications of variations of future expenditure.

Figure 1.13

**The Typical Pyramidal Management Structure with the Nature of Control
Exercised at Each Level**
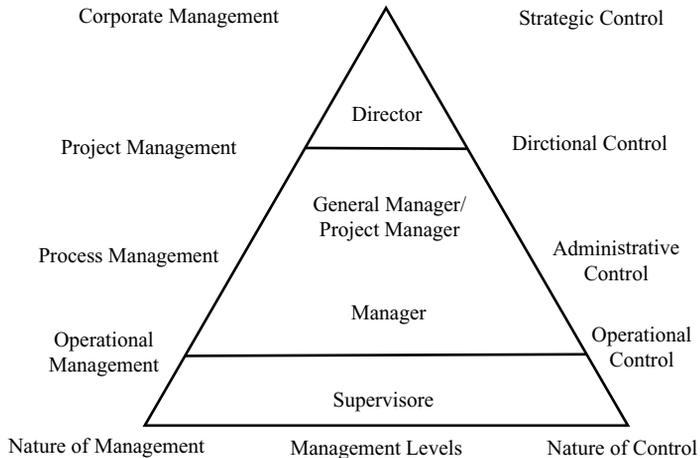
Directional control at general manager's/project manager's level. It helps in formulating and directing the policies for the achievement of project objectives by:

- Analyzing project time cost behaviour and making decisions on time saving when required;
- Reviewing project costs and profitability, and making profitability improvement decisions concerning wastage reduction through rigorous cost control, value engineering techniques, cost benefit analysis, workers' incentive schemes and alternate methods of construction which cost less;
- Auditing management's performance;
- *Strategic control at corporate level.* It provides information that can assist management in formulating corporate strategies by:
  - Determining overall profitability;
  - Budgeting and allocating funds and resources; and
  - Updating the company's planning norms and unit rates for securing future works.

An effective control system generates information that can improve the productivity of men and materials, economize the employment of resources, enable the understanding of time and cost behaviour and add value to the quality of work. It also provides early warning signals of ensuing dangers, updates the resource planning and costing norms, prevents pilferage and fraud and assists in formulating bonus/incentive schemes for motivating people. It may be noted that the prerequisites for effective functioning of the monitor are the management backed drive for making the site executive integrated plan conscious and by creating a well-coordinated harmonious environment. Further, a computer is an efficient invaluable tool to assist the monitor in the performance of his duties but it is not a substitute for the planning function.

During project implementation, the plan-do-monitor-communicate-replan (when necessary) is a continuous process. In this context, the term planning broadly includes the plan making, scheduling and controlling processes. The Planning, Scheduling and Controlling methodology employed for managing project scope, time, resources, costs and risks are loosely called Project Management Techniques, these are the focus of this book.

APPENDIX A

Construction Project Manager Competency Skills

❑ A.1   INTRODUCTION AND SCOPE

Modern construction projects are complex and risky by definition. They are managed by individuals, whose work is to deliver projects. It is the project manager and the project team, who skillfully leads the multi-disciplinary, multi-functional team, in order to accomplish the assigned mission. The project team consists of brain power that can vary with the nature of project. The 'facts of life' in project work (crises, uncertainties, risks, and pitfalls) test the mettle of these managers in a continuous manner. Clearly this is not the field for the timid and the untrained. Competency of a construction project manager to manage a given project raises many questions such as competency requirements, and need for skills upgradation. Most of these questions are covered under the following sections:

* Construction Project Manager Competency Requirements
* Competency Considerations of a Project Manager for a Specific Construction Project
* Skills Upgradation Options

❑ A.2   CONSTRUCTION PROJECT MANAGER COMPETENCY REQUIREMENTS

Competence implies that the knowledge, skills, and essential personality traits are required for managing the project. The success of a project relies on competency of the construction project manager.

Competence = Knowledge (qualifications)
> \+ Skills (ability to do a task)
> \+ Leadership characteristics and Interpersonal Skills
> \+ Demonstrable past performance
> \+ Personal Attributes

Professional competency development is a continuous process that is commonly termed as 'Continuing Professional Development (CPD)'.

Competency Requirements Model.   Construction projects are unique that is no two projects are alike. In order to fulfill the assigned role effectively and efficiently, an ideal construction project manager must have project management skills, technical expertise, environmental management capabilities, leadership qualities, and interpersonal acumen. The model shown in **Figure A.1** broadly, represent the competency requirement of a construction project manager in managing commonly encountered construction projects. These knowledge areas and skills overlap in some projects.

Figure A.1

Construction Project Management Competency Requirements' Model
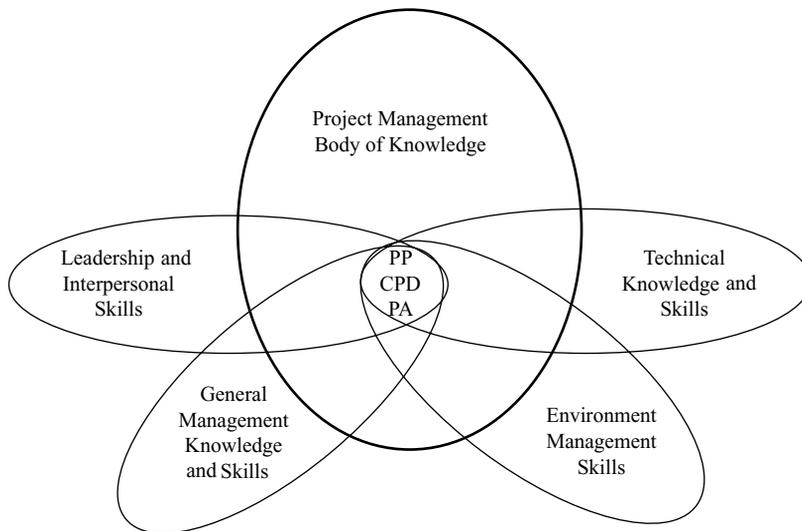
PP - Past Performance; CPD - Continuing Professional Develpment; PA - Personal Attitude

Project management knowledge and skills.   These include management of integration, scope, time, resources, cost, quality, procurement, human resource, communication, risks and overall coordination. In addition, the construction specific projects also include contract administration and contract claims management.

General management knowledge and skills.   These include project formulation processes along with management of finance, purchases, marketing, commercial and labour laws, logistics and supply chain, general management principles, personnel administration, workers' health and safety practices, and information technology.

Environment knowledge and skills.   Environment means the operating surroundings of a project. It includes management of changes in external and internal situations of the environment. The external environment is affected by changing conditions in political, legal, economic, natural, ecology, and health etc. The internal environment crisis could be due to project management plan deviations, communication failure, resources supply breakdown etc.

Leadership and interpersonal skills.   It covers attributes, such as leadership traits/qualities, devotion to work, effective communication, motivation, negotiation, community development and conflict management, and problem solving approach.

Technical management knowledge and skills.   It implies construction project related; technical and design practices, construction standards, and supporting disciplines, such as legal, inventory management, marketing, logistics, contracting, and new product development.

Past performance, continuing professional development (CPD) and personal attributes.   These are at the core of the competency requirements. Past experience determines the performance of an individual. A construction project manager should be a person with at least a degree or equivalent in engi¬neering, architecture, or quantity surveying. He should have relevant technical management qualifications and construction experience, of at least few years as a senior person in similar projects. CPD shows the development of an individual after obtaining his engineering and management qualifications. In particular, the checklist of desirable attributes of a project manager is given below:

- Attitude—an open positive 'can do' attitude.
- Common sense—an ability to see things as they really are and to pick sensible, effective, straight forward solutions.
- Open mindedness—being open to new ideas, practices, and methods.
- Adaptability—an ability to anticipate and adapt to changes.
- Inventiveness—an ability to discover innovative strategies and solutions.
- Prudent risk taker—a willingness and ability to identify, understand, and manage the risks.
- Fairness—a fair and open attitude, which respects all human values.
- Commitment—a very strong overriding commitment to the project's success, user satisfaction, and project team working.

If there is one single attribute of a project manager, which should be regarded as absolutely essential, it is that of commitment to the project's success. Without this, other personal attributes, no matter how admirable do not necessarily benefit the project.

❑ A.3   COMPETENCY CONSIDERATIONS OF A PROJECT MANAGER FOR A SPECIFIED CONSTRUCTION PROJECT

Some existing standards for the assessment of a project manager's competence.   The project management professional societies throughout the world take into account different approaches to define the competence that is required for managing projects. Broadly, there are two streams of thought on competency requirements.

Project Management Institute (PMI®, www.pmi.org), based in USA, through its body of knowledge (PMBOK 2013) , PMP certification program and its Project Manager Competency Development Standard, advocates process management based approach to competence. Association for Project Management (APM, www.apm.org.uk or info@apm.org.uk) through its body of knowledge and APM certification program focuses on the functions the project managers need to perform.

But the accreditation/certification by the above societies are not adequate to meet the competency requirements of all types of the construction projects. What is needed is competency for managing a given construction project. Readers may visit the above mentioned and explore other websites for more details.

Assessing Competency of a Project Manager for a Specified Construction Project.   While, selecting a competent construction project manager, the traditional approach of a corporation is to look for the appropriate technical qualifications, relevant experience, and past track record. These qualifications may include a combination of engineering degree or PE/IPEA registration, PM/MBA or equivalent qualifications, membership of societies and demonstrated performance on similar projects. Most of the developed and developing countries have developed standards for Registration of their Professional Engineers and are member of the International Professional Engineers Agreement (formerly, known as the Engineer Mobility Forum). Engineer Mobility Forum of the East Asia has laid down certain requirements for accrediting Professional Engineers. To quote an example, Institution of Engineers India, who is a member of the EMF has specified eligibility criteria for becoming a professional engineer. These criteria include, recognized bachelor degree in engineering or equivalent, minimum seven years of professional experience, minimum two years of professional experience in significant engineering activity, satisfactory level of Continuous Professional Development (CPD), member of a recognized professional institutions or society, and, good character with demonstrated commitment to the code of ethics.

For a given project, corporate should customize the selection process. Because, it is rare to find an experienced project manager with excellent knowledge and skills in all parameters of competency requirements who and can manage all types of construction projects.

❑ A.4   SKILLS UP-GRADATION OPTIONS

Education can be defined as the organized and sustained instuctions that are designed to communicate a combination of knowledge, skills, and understanding valuable for all the activities. Training focuses on the development of competency skills that will be applied to a particular task or in a

particular context. The education and training for the development of the Total Project Management processes can be divided into the following categories:

- Academia-directed project management education in the institute or distance learning approach.
- Corporate-directed in-house project management training, seminars conducted by experts or online distant learning teaching ending up with contact seminars.
- Own time Individual-directed self-learning education and training using published literature, distance learning and virtual class room delivery approach.

The unprecedented rate of emergence of new technology, calls for continuous upgrading of managerial skills. The construction projects, thus, should resort to outsourcing to just-in-time training rather than live with just-in-case-a-situation-arises education type. The emerging trend is to develop competencies of managers based on corporate goals. Training performance are subject to return-on-investment analysis, and not just on the 'reaction sheets'' that are compiled at the end of a training workshop.

The various methods that can be employed for upgrading managerial skills for project management are:

1. Re-engineer corporate heavily-staffed training centers (where existing) by changing their role as 'training coordination centre and conducting job-related training by employing expert/consultants/monitors.
2. Use online short duration delivery methods, such as the Internet, teleconferencing, and customized programme. These enable access to up-to-date knowledge, as and when required, rather than waiting for several weeks for a new training session to begin.
3. Encourage self-initiated learning practices in managers by using distance learning programs, especially during non-traditional delivery hours such as evening/weekend classes. This will help them in gaining new insights, skills, and tools, which are needed to keep the competitive edge, in the fast-paced global market for shaping their future career. In turn organisations, also gain from their acquired knowledge.
4. Corporate firms can adopt construction management training institutions/consultants to provide customised state-of-the-art knowledge and know-how, and act as mentors to managers as the project grows.
5. Academic institutions and universities can impart customized training to managers on construction related subjects at postgraduate level, as and when required. In addition, universities can conduct courses such as 'Master in Project Management'.

The specially designed short duration contact programme, conducted by academic or training institutions, in virtual or cloud-based environment, can meet the needs of the construction corporate. It can also provide the win-win situation for all the participants. For the learner, cloud/e-mail based online distance learning, can reduce travel time, unproductive costs, enables delivery at home without disturbance in job assignments. It can also provide training to more people at less cost and the learners can get training at cheaper rates.

Planning Project Works Scope and Its Integration Processes

The project charter outlines the project scope. The project scope defines the development works that must be undertaken in order to deliver a facility or a product or a service (hereafter referred as facility) within the specified attributes. These attributes are expressed in terms of related time, cost and other constraints. Project facility development work scope aims at ensuring that all the construction works are done as per design and specifications to ensure the achievement of the stated purpose or functionality of the facility.

The project facility work-scope planning focuses on the scope of work and its components (deliverables), generally identified with its functional requirements, design and drawings, the facility production quality specifications, work breakdown structure (WBS), costing in Bill-of-Quantities (BOQ), and the production method statements. The contractor(s) deliver the entire facility or the contracted part of the work scope as per the terms and conditions of their contract.

The project work scope planning considers various options for the execution of project work before making implementation decision. There are several possible approaches for the execution of the project scope of work. These include the departmental approach, contractual approach and consultant approach. Further, there are many types of contracts like fixed price, cost-plus, service procurement, and PPP/ BOT varieties. Each has its own merits and limitations. The guidelines for administration of construction contracts and the dispute resolution mechanism is briefly covered in **Appendix M**.

The simple definition of the project scope has in-built depth while managing. It defines the project work scope with its specifications. It integrates the scope execution plan with its attributes of completion time, resources, and costs. Thereafter during implementation, it controls the deliverables along with their attributes to ensure that they meet the product specifications and project's purpose.

Project scope integration plan interlinks the work scope and the associated features. The plans of the associated features, which forms part of the project scope integration plan include project time, resources, cost, quality assurance, risk response methodology,risk mitigation strategy and project management information system (see **Figure 2.1**). This integrated plan is also called a project management plan.

This chapter focuses on project work scope and its integration planning approach. It also provides an overview of the processes and techniques covered in the book. This chapter is divided into the following sections::

Figure 2.1

Project Work Scope and Integration Planning Flow Diagram
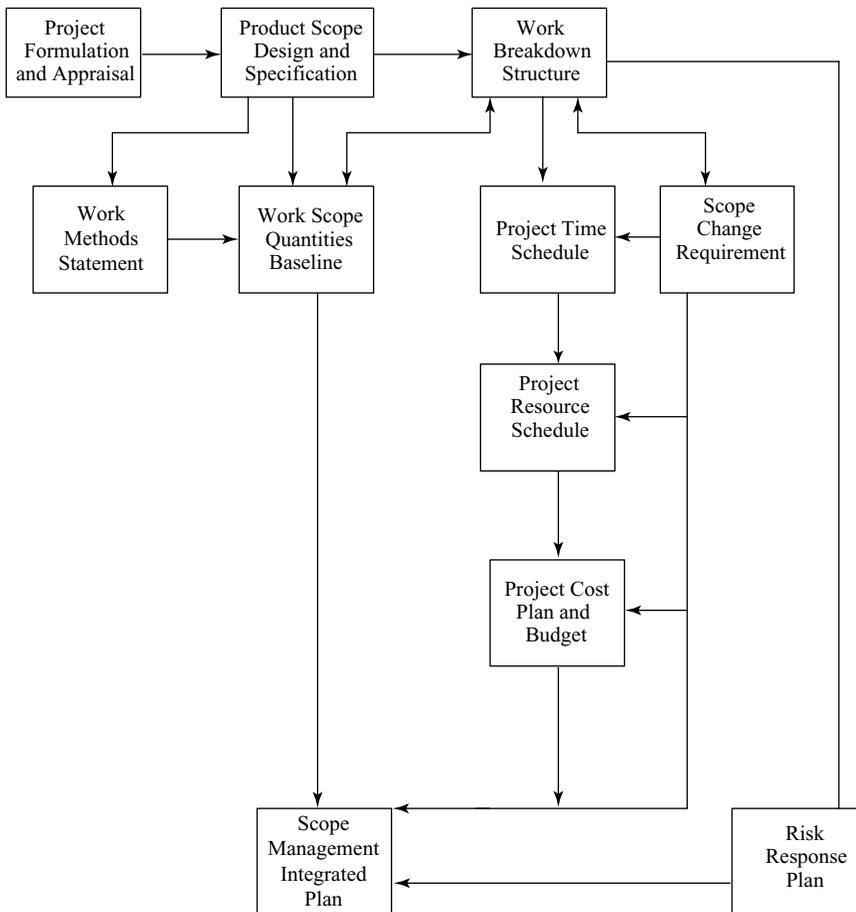
1. Project Work Scope Planning
2. Project Work Scope Construction Procurement Options
3. Work Construction Method Statements

4. Project Work Scope Integration Planning
5. Role and Function of Chief Planner

The Project Success Strategy Development is outlined in **Appendix B**.The planning of project time, resource and cost is described in **Chapters 3–12**. Methodology for controlling project work scope and its attributes are covered in **Chapters 13–18.** The contents of this chapter should be viewed as guidelines. The methodology covered here should be suitably modified to conform to the varied nature of construction projects.

❑ 2.1   PROJECT WORK SCOPE PLANNING

2.1.1   Project Work Scope Planning Processes

If the project is approved for implementation, the project formulation phase generally concludes with the documentation of the project charter or work operation order and the selection of the project manager. It covers the purpose for undertaking the project and the initial outline organisation. It highlights the broad scope of the construction work (including deliverables and requirements) and defines the project time, cost and quality objectives. It may also include project assumptions and constraints, inclusions and exclusions, an outline execution methodology, scheduled milestone plan, major resource forecasts, budgeted cost and cash flow forecasts, and potential risks and problem areas.

The project facility development work scope focuses only on the works to be executed. It aims at ensuring that the project includes all the works conforming to stipulated design, drawings, specifications and BOQ, and is concerned only with the work required to complete the project successfully.

Work Scope Planning commences after finalization of the Project Charter. The scope planning and controlling processes along with the tools and techniques and outcome are given in **Table 2.1**.

2.1.2   Formulating Scope Requirements

'Requirements' are the statement of the facility needs that a project must satisfy. These include the quantified and documented needs of the stakeholders. These requirements include but are not limited to the functional requirement of the facility, user requiremetnt, technical requirements, initial constraints and assumptions. In the initial stages of the project, there may be a large list of requirements. But these 'Requirements' must be formulated keeping in view that during implementation, these are to be controlled. It is therefore necessary that the requirements are fully documented and are understood by the persons responsible to control these.

In the project context, requirements can be divided into facility scope features and functional requirements, and project scope attributes requirements. Requirement formulation aims at defining and documenting the functional requirements of the facility, the needs of the client and other stakeholders to accompolish meet the project objectives. Requirement management processes include capturing, analysis and testing the documented statement of stakeholders and user needs.

Table 2.1

Work Scope Planning and Controlling Processes

Work scope planning and Controlling processes	Tools and techniques	Outcomes
Formulating requirements	Project charter, stakeholders' interests, SWOT analysis, workshops and opinion & surveys	Project scope statement, project objectives
Defining Facility Development work scope	Design & drawings, construction specifications, bill of quantities	Work scope definition
Developing work breakdown structure	WBS techniques	Scope baseline Activities lists
Preparing construction method statements	Construction practices, specifications	Construction practices
Deciding procurement options	Examining departmental & contractual work execution options, organising resources mobilisation	Mode of execution decision, construction site mobilisation
Developing a project mnagement integrated plan	Integrating project time, resources, costs, quality & risk management plans.	Project management plan
Verifying and controlling works execution and acceptances.	These are covered in Chapter 13.	

In simple words, 'Requirements' are the statement of the facility needs that a project must satisfy. The basic input in the formulation of these requirements is the project charter and the discussion with the stakeholders prior to finalisation of the project management plan

2.1.3   Project Scope Planning Tools and Techniques

The work scope planning tools and techniques include but are not limited to the following:

1. ***Development of designs, drawings and specifications***. They provide the characteristic features and modes of realisation of the deliverables.
2. ***Estimation and structuring of quantities of work***. The Bill-of-Quantities (BOQ) coupled with the Statement-of-Costs (SOC) become the project work scope baseline. Production method statements are covered in **Section 2.3**.
3. ***Work breakdown structure (WBS)***. It decomposes the project work scope into deliverables and splits up deliverables into various levels such as sub-projects or task groups, tasks, work packages and activities.

2.1.4   Design Planning

Designs form the basis for determining the functional fitness of the proposed facility, development of the drawings, estimation of cost of the project and the quantity of work, deciding upon

construction time and forecasting cash-flow. During the design process, project information is collected, analysed, communicated and recorded for incorporation into the proposed scope of work (see **Table 2.2**).

Table 2.2

Typical Building Design Management Processes.

Project Phase	Design Function	Output
1. Inception	Conceptual design	Conceptual sketches, proposal analysis, recommendations
2. Feasibility	Schematic design	Schematic drawings, scope description, cost projections
3. Project planning	Design development	Detailed designs
4. Construction procurement	Provision of good-for-construction design and drawings, and specifications	Detailed drawings, bill-of-quantities, specifications, revised cost projections, milestone completion time schedule
5. Construction	Scope verification	Drawing schedules, shop drawings and specifications
6. Post construction close up	Operation and maintenance system	As-built drawings, operation and maintenance data, equipment warranties, project report.

Designing and drawings development follows three sequential processes—schematic design, design development and detailed Good for Construction (GFC) drawings.

Schematic design phase.   In the project feasibility stage, the designer/architect evaluates the client's requirements. After discussing the alternatives with the client, the designer then prepares a conceptual design brief for the client's approval. The schematic design brief includes site plan, facility drawings, outlined specifications and conceptual design for structural, electrical, mechanical and other connected systems. The design document may include preliminary sketches, diagrams and other written documents, so as to indicate the project scope, time and cost and describe the outline of the construction methodology.

Design development phase.   This phase commences after approval of schematic designs. The emphasis in this phase shifts to the details of constructability, system integration and aesthetics. The drawings in this phase include planning, elevation and section of the facility. It also includes the design of the external services.

Drawings development phase.   The drawings show a graphical representation of the design intent, usually on a two-dimensional surface, for the purpose of conveying data about a specific portion of a project. Drawings indicate the relationship between elements by showing location, identification, dimensions and sizes, connection diagram, shape and form for each material, as-

sembly, component and accessory. Drawings are used in many ways by the concerned persons. The traditional users include architect/engineers, owners, contractors and sub-contractors.

Drawings may also be required by various agencies like financial institutions, lenders, insurance agencies and licensing authorities. The type of drawings vary with the purpose of the user and the construction phase. Drawings are organised into sets or folders. A drawing-set is a collection of sheets or files of drawings related to a product, facility or service. A well-organised drawing set enables easy retrieval of information, assisting coordination and avoids duplication and omission of information.

The organisation of drawing-sheets into sets depends upon many factors such as project type, size, disciplines involved, construction sequence and delivery systems. There are many systems for drawings sets organisation such as those developed by reputed institutions like the Construction Specifications Institute (CSI) of USA and Royal Institute of British Architects (RIBA). Some projects organise drawing sets by A/E disciplines and/or WBS pattern. The current trend is to computerise sets by designing suitable identification codes for various components and then assign these with the desired drawings, quantities, specifications and other related information. The Internet makes it possible to transmit computerised sets of drawings promptly to all concerned.

2.1.5 Specifications

These define the qualitative requirements for the products, materials and workmanship upon which the design is based. The specifications also describe the inspection and acceptance procedures. Specifications denote requirements of the owner. Technical specification documents include: material specification, construction requirements, and construction method and acceptance criteria. Technical specifications may take several forms and one or more of these may be selected. Examples of these are as follows:

- Describe in words about the work to be done, the quality of materials and workmanship, the method of construction, the method of testing, etc.;
- Standards published as reference specifications for construction material and processes by government approved professional bodies and engineering societies;
- Construction drawings showing the plan, elevation, sections of relevant structural and architectural elements in scale, the levels, perspective view, materials, methods, etc. according to which the construction will be done; and
- Client's developed standards.

Almost every country has its own construction standards and some of them also follow other countries' standards. The well-known organisations publishing standards include: Bureau of Indian Standards, British Standard Institute, Construction Specification Institute, USA, and International Standard Organisation, Geneva. The Construction Specification Institute can be accessed on http://www.csinet.org and MasterFormat of specifications on http://www.masterformat.com/revisions/index.

2.1.6   Bill-of-Quantities Structure

The project scope of work is measured in quantities and related costs. A preliminary cost estimate is prepared by a client in the initial stages for tendering the works. It follows a structured approach. The structure of a detailed estimate takes many forms. These forms vary with the nature of the project, the type of contract, the company policy and the client requirements. The three typical well-known forms of Bill-of-Quantities (BOQ) in the structuring estimation items are given in **Table 2.3**.

Table 2.3

**Three Well-known Estimations Structures for
Building Construction Projects**

R S Means	Engineering News Recorder	Construction Specification Institute
Sub-structure	Site work	General requirements
Super-structure	Foundations	Site work
Exterior enclosure	Floor systems	Concrete
Interior construction	Interior columns	Masonry
Conveying system	Roof systems	Metals
Plumbing system	Exterior wall	Wood and plastics
HVAC system	Exterior glazed openings	Thermal moisture
Electrical system	Interior wall systems	Doors and windows
Fixed equipment	Doors	Finishes
Special foundation	Specialties	Specialties
Site construction	Equipment	Equipment
General contingencies	Conveying systems	Furnishings
Other related costs	Plumbing	Special construction
	HVAC	HVAC
	Electrical systems	Mechanical
	Fixed equipment	Electrical
	Special electrical	
	Marks up	
	General contingencies	
	Other related costs	

In particular, each head of the BOQ is further decomposed into detailed items of work, where necessary. Extracts of BOQ of items of work in foundation construction of a residential building module (original modified) aregiven in **Table 2.4**.

2.1.7   Work Breakdown Structure (WBS)

Work Breakdown Structure (WBS) is a 'deliverable-focused hierarchical grouping of project. It defines the total work scope of project'. Deliverables are tangible, measurable parts of the project.

Table 2.4

Bill of Quantities: Foundation of a Residential Building*

Item No.	Description	Quantity	Unit	Rate ($)	Amount ($)
A.1	Excavation in foundation includes disposal of earth within the work site, leveling and dressage and compaction of final source.	44 400	M^3	5.00	222 000
A.2	Backfilling and compaction around foundation in layers not exceeding 30 cm with excavated earth	13 320	M^3	5.00	222 000
A.3	Earth filling and compaction in plinth with approved soil in layers not exceeding 30 cm level	33 855	M^3	20.00	677 100
A.4	Anti-termite treatment for bottom and sides of foundation plinth wall as per approved manufacturer's specifications	59 274	M^2	7.50	444 555
A.5	Painting with 2 coats of bitumen paint to foundation sides and plinth wall surface	75 591	M^2	2.45	185 198
A.6	Laying of polythene sheet 1000 G as separator between earth and concrete, and earth and ground floor slabs	65 157	M^2	1.00	65 157
A.7	75 thick blinding concrete Grade M-100 in foundation with sulphate resisting cement	1998	M^3	95.05	189 910
A.8	Reinforced concrete Grade M-250 in foundation and plinth walls with sulphate resisting cement including inserts, form-work and including expansion joints as necessary but excluding reinforcement	14 643	M^3	163.50	2 394 150
A.9	Same as Item A.8, but for ground floor slab	3146	M^3	144.95	455 975
A.10	Mild steel weld mesh reinforcement as per BS 1221 for ground floor slab	72.26	Ton	1518.1	109 691
A.11	High strength deformed bars reinforcement as per ASTM 1-615 Grade 60 or equivalent	673.33	Ton	1095.00	737 292

*Original modified.

Non-deliverable items of work such as the designing, resources procurement and financing of project etc. are not included in the WBS. The project work can be broken down into manageable parts

arranged in a hierarchical order into levels of sub-projects, tasks, work packages (WP) and activities as show in **Table 2.5**.

<div align="center">

Table 2.5

</div>

Typical Cross-section of a Highway Construction Project

Level	Description	Main Criteria
1	Sub-project level	An independent, deliverable end product requiring processing of multitask having large volume of work.
2	Task level	An identifiable and deliverable major work containing one or more work packages.
3	Work-package level	A sizeable, identifiable, measurable, cost-able and controllable work item/package of activities.
4	Activity levelww	Identifiable lower-level job, operation or process, which consumes time and possibly resources.

Notes:
- Project title can be defined as level 0.
- Some academicians and practitioners restrict the work breakdown process into tasks levels. Others go down to work packages or activities.

Each descending level of WBS signifies an increasingly detailed description of the elements of the preceding project level (see **Figure 2.2**). WBS development methodology is detailed in **Chapter 3**.

WBS is the core upon which project management processes are built. A good quality WBS should meet the core requirements for which it is created. These requirements include deliverable orientation and hierarchical decomposition into levels covering the full scope of work at least till work packages level that support deliverables. It can be further split up into activities, but excludes all that is not within the scope. WBS assists in codifying in digit hierarchical order down to activities. It enables the preparation of WBS dictionary and serves as input for the development of work scope definition, identification of activities, planning of time schedule and cost breakdown. It helps in project management software application. The WBS applications are covered in **Appendix C.**

Example: WBS of a highway project. The development of WBS is illustrated with examples from a highway construction project. The scope of work in this BOT highway construction project valued around Rs. 750 crores, included designing and construction of pavements, flyovers and two toll plaza complexes. The pavement work was divided into 29 sectors, each varying from between half to three-fourths of a kilometer of the road stretch with typical 6-lane cross-sections. Each sector consisted of pavement work, drainage and culverts (see **Figure 2.3**).

The 'pavement work' was divided into five parts: left service lane, left main lane, median divider at the middle, right main lane and right service lane. The WBS of the 'pavement work' of this project is developed, step-by-step, in the subsequent paragraphs.

Figure 2.2

Typical work breakdown structure configuration.
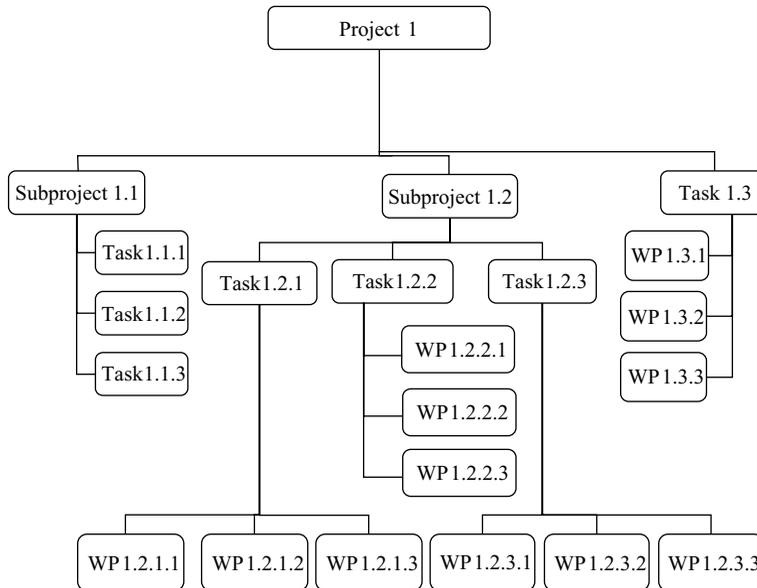
Sub-projects level. Sub-projects are derived by decomposing the scope of project work into independent large-volume mini-projects or task groups, which can be progressed in a systematic manner, without interference from other work groups (see **Figure 2.4**).

Task level. The project or sub-project work can be split up into various tasks. A task is an identifiable and deliverable major work (see **Figure 2.5**).

Work-packages level. A project task can be further sub-divided into one or more work packages. Each work package contains a sizeable, identifiable, measurable, costable and controllable package of work (See **Figure 2.6**).

Activity level. A work package can be further broken down into various identifiable jobs, operations and processes, which consume time and possible resources which are necessary for its completion. Each one of these is called an activity. See **Figure 2.7** for the activities in a section of the highway pavement work.

Other examples of work breakdown structure. WBS can be represented in three familiar forms such as: hierarchical inverted tree structure, numbered levels table and task matrix format. The following list provides the illustraters WBS of some of the projects given in **Chapter 3**:

Figure 2.3

Typical Cross-section of a Highway Construction Project
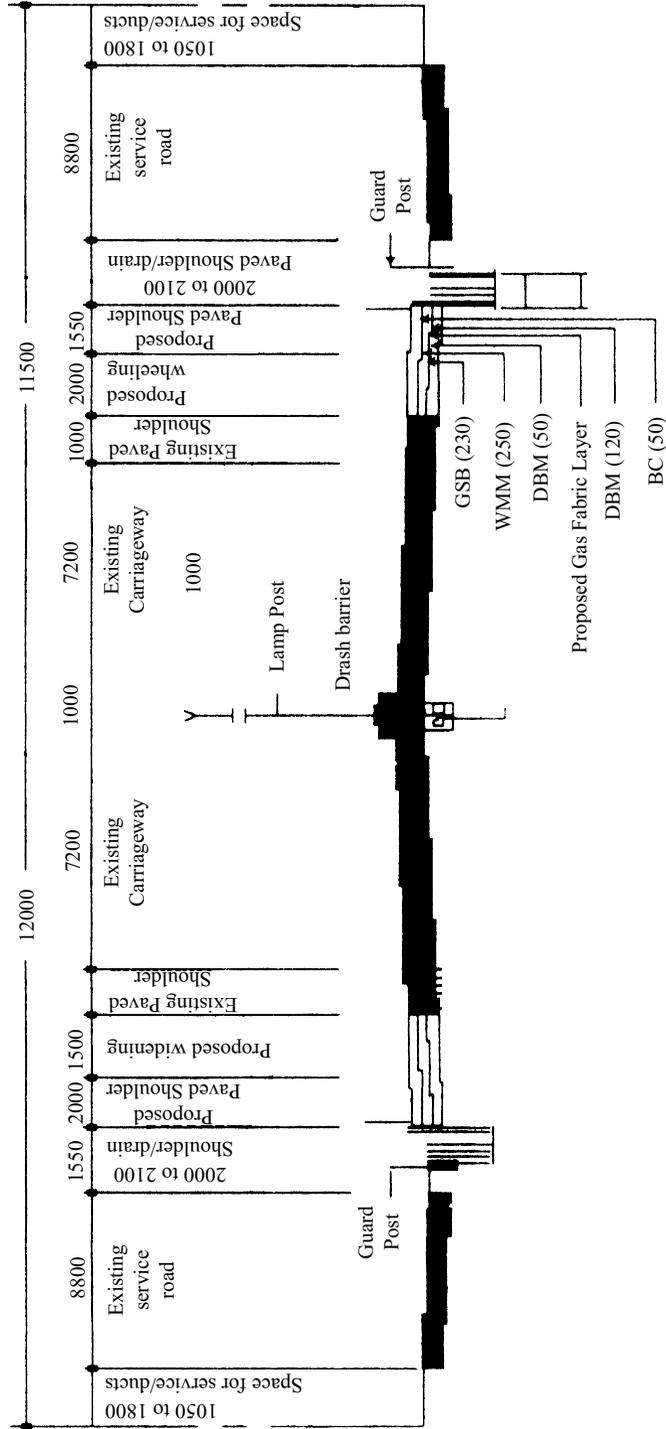
Figure 2.4

Project Work Breakdown into Sub-projects A Highway Construction Project
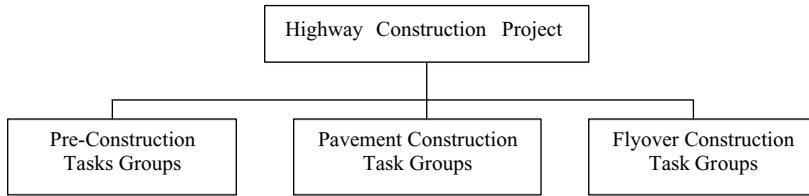
Figure 2.5

Project Work Breakdown Tasks (Deliverables) Highway Construction Project
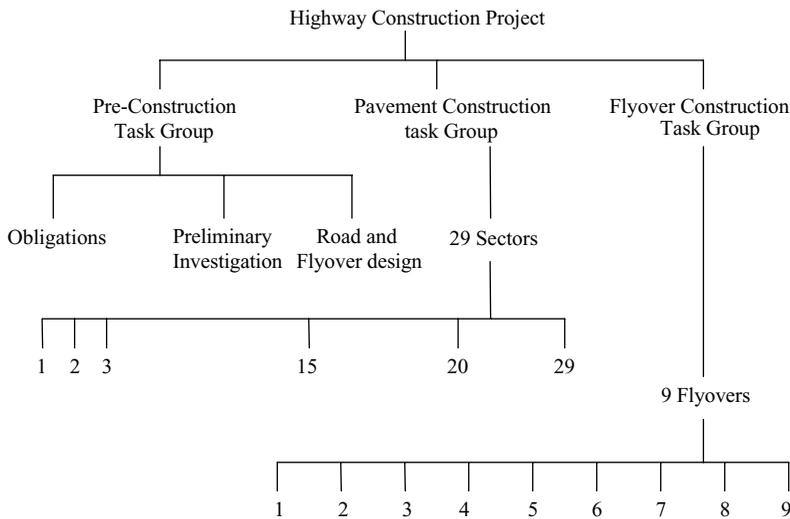
Nature of project	WBS patterns	Exhibit references
Simple projects: Pumping station construction	Tree-structure and numbered levels table	Exhibit 3.4
Complex projects: 2000 Housing Units Project	Tree-structure	Exhibits 3.1–3.3
Simple repetitive projects: Factory project	Task matrix	Exhibit 3.5
Complex repetitive projects: Education building complex	Combination of tree-structure and task matrix	Exhibits 3.6–3.7
Complex program: New cantonment construction	Tree-structure	Exhibits 3.8–3.10

It may be noted that in the beginning of a complex project, it may not be feasible to create fully decomposed WBS due to non-availability of the appropriate information. In such cases, initial

Figure 2.6

Highway Pavement Construction Tasks–Group

29 Sectors

| | | | | | |
| 1 | 2 | 3 | 15 | 20 | 29 |

A Construction Sector Tasks and Work Packages

Drains   Lanes   Culverts

Left Service Lane   Left Main Lane   Median   Right Main Lane   Right Service Lane
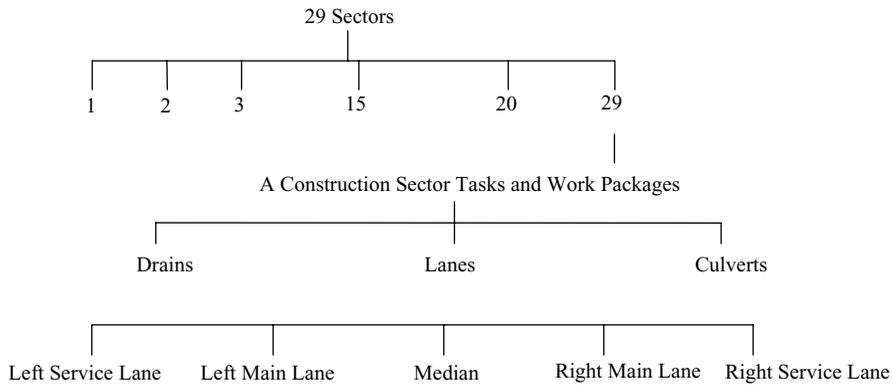
Figure 2.7

Nature of Activities in Service Lane of a Highway Project

S. No.	Service Lane Construction
1.	Clearing and grubbing (SL)
2.	E/w in cutting (SL)
3.	E/w in filling (SL)
4.	Sub-grade (SL)
5.	GSB (SL)
6.	WMM (SL)
7.	DBM (SL)
8.	BC (SL)
9.	Road barriers, signage, road marking, lighting and finishes

(There were about 6,800 activities in the highway construction project.)

decomposition levels are partial, and the full decomposition can be undertaken at a later period when the required information is known. To quote an example, take the case of a mega-size BOT Express Highway Project involving 'six lanes road pavement construction of length 225 km with service roads on both sides'. The project was divided into six sectors nearly equal in length, each sector separated by a major structure. The various structures in the project included grade separators/flyovers, major and minor bridges, elevated roads, various types of culverts/underpasses and

connecting longitudinal drains. The WBS of this project developed in 3-levels for developing a preliminary construction plan is shown in **Exhibit 2.1**

❑ 2.2 PROJECT WORK SCOPE CONSTRUCTION PROCUREMENT OPTIONS

2.2.1 Construction Procurement Options

There are several approaches possible for constructing facilities in a project. At one extreme, an Employer/Client wishing to construct a facility may undertake to execute the work through his organisation (departmentally). The other end of the spectrum is to get the entire work done on turnkey basis through a contractor. There are many in-betweens. In general, work scope construction can be divided into three main categories, i.e. contractual approach, departmental approach and consultant including professional construction manager (CM) approach.

2.2.2 Departmental Approach

The in-house or departmental execution of works is carried out by the concerned organisation with its own resources. India's border road construction is mostly done by the Border Road Organisation and it has done commendable work in the high altitude areas. This approach has certain advantages. The employer/client maintains direct control over the operations and can change the scope of work to meet the changing situation. It enables design and production secrecy. It adds capacity in the organisation. But, it may needs additional investment and resources as the organisation executing works departmentally has to build up its own competency in the various construction activities. Mostly construction works are executed through contracts.

2.2.3 Contractual Approach

Construction projects, whether small or large, cannot be executed with in-house resources unless the employer/client himself is a contractor. Construction contractors form the backbone of the construction business as they execute most of the construction work. The contractual option has many advantages such as:

- Contracted works usually cost less than the departmentally executed work.
- In contracted projects, the owner utilises the services of the contractor experts/specialists/suppliers rather than training his own staff and facing teething problems in specialised fields.
- The employer/client's risk of variations in the cost is covered in contract work.
- The employer/client can limit his manpower to supervisory roles.
- The employer/client saves on the investment needed to procure the expensive capital equipment.

The competitive modern construction business requires special resources for different types of construction work and the contractors tend to specialise in a specific area of construction. From this

Exhibit 2.1
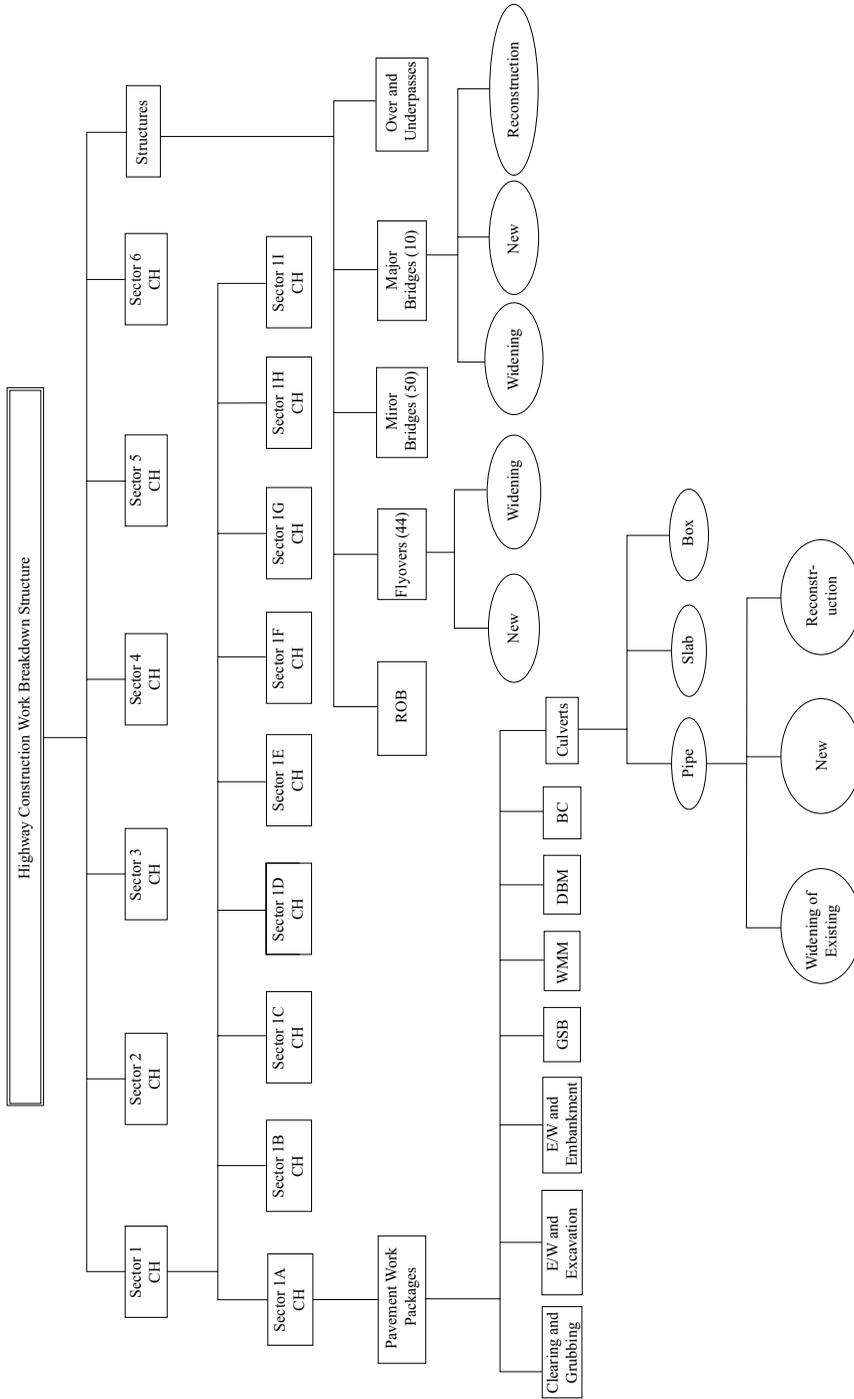
Note: The above WBS can be further decomposed to activity levels after the details are available.

functional angle, the contractors can be classified into different categories. These include general contractors, building contractors, specialist heavy infrastructure contractors, specialist industrial works contractors and contractors offering specialist utility services including electrical, water supply, sewage disposal and HVAC services. But the administration of contracts is not trouble-free as the contractor dispute are unavoidable, see **Appendix M**.

2.2.4 Types of Construction Contracts

Various types of contracts have been evolved to suit the various situations, compliance with the legal requirements and to meet employer/client's needs. Types of contracts include:

1. Fixed price or lump sum construction contract is follows:
    Fixed price with escalation price adjustment,
    Fixed price with incentive targets, and Fixed price privatised infrastructure
2. Cost-plus percentage fee such as:
    Cost-plus fixed fee,
    Cost-plus guaranteed maximum,
    Cost-plus guaranteed maximum and shared savings, Cost-plus incentive (award fee), and Cost and cost sharing.
3. Public Private Participation (PPP) infrastructure projects; and
4. Resource and service procurement.

At one end of the range is the fixed price lump sum or turnkey type of contract under which the client has a fixed price for construction works. At the other end is the actual cost-plus a fixed-fee type of contract. Between these, there are various types of contracts, such as the incentive types of contracts, and the bonus-penalty type of contract. It should be noted that there are no demarcation lines for using various types of contracts. In construction projects, one or more types and forms of contracts can be used for different types of work.

Fixed price/lump-sum contracts. In a fixed price contract, the contractor undertakes to construct the tendered works at a fixed price subject to adjustment for deviations ordered by the owner according to the terms of contract. In a lump-sum contract, the scope of work is based on the tender documents which include: time stipulation for construction, drawings, specifications and BOQ. While quoting lump-sum contracts, the contractor prepares detailed estimation of cost and takes risk that the actual cost shall not exceed the bid amount. Generally construction projects like residential buildings, road construction, sponsored by government use lump-sum type of contracts.

Cost-plus-fee contracts. The employer/client agrees to pay all costs incurred by the contractor in the execution of works plus an agreed fee to cater for contractor overhead and profit. This form of contacts are generally employed in fast-track type of turnkey construction, to save time by processing works based on part design and drawing, without waiting for completion of entire de sign package. Cost-plus-fee contracts also find application in specialised turnkey works like power plants.

Public Private Participation (PPP) Build-own-transfer infrastructure projects contracts.   The Build Operate Transfer (BOT) family includes a variety of techniques such as: the BOT, the Build Own Operate (BOO) and the Build Own Operate Transfer (BOOT). The basic concept behind the BOT is that infrastructural works can be procured by the government or the public sector, with private sector turnkey participation. The cost of these projects gets recovered by the builder from the consumer over a fixed period of time through a government-backed arrangement.

Resource and service contracts.   These deal with the procurement of resources and services by contract or supply order from various business firms like materials suppliers, manpower recruitment firms, plant and machinery hiring firms, banks and financial institutions.

2.2.5   Contractual Arrangements

There are wide varieties of contractual arrangements; the three main categories are outlined as follows:

1. *Build-only contracts*. In these contracts, the architectural and engineering design and drawings are provided by the Employer/Client to the contractor at the time of tendering as a part of the contract document. Most of the public works contracts are of this category. Build-only contracts can be further classified into lump-sum contracts, measurement contracts and cost reimbursement contracts.
2. *Engineering procurement* and construction contracts. These are package-deal turnkey-type fixed-price contracts that include: design, resources procurement, construction and commissioning of the proposed facility. Turnkey contracts are based on preliminary information provided by the owner. This preliminary information includes: the purpose of the facility, its contemplated layout, contractual requirements, relevant sketches and performance specifications. Mostly large-sized jobs and specialised industrial plants, where time is of paramount importance, are undertaken on a turnkey basis.
3. *Buid-own-transfer PPP contract*. The growing need for speedy implementation of infrastructural works, especially in developing countries which have a financial resource crunch, has given rise to new practices of procuring high-cost engineering capital works. The emerging trends are to use BOT family contractual arrangements. Such infrastructure works include: highways seaports, airports, railways, power plants, clear water supply, and waste and sewerage disposal. Mostly, the upsurge in the BOT family is driven by the government need to reduce public expenditure by involving private financial participation, while at the same time, speeding up economic growth.

2.2.6   Sequential vs. Fast Track Approach

Sequential approach. Traditionally, the management process follows a sequential approach. It begins with the owner's decision to procure a facility. The design is then finalised by the architect

engineering associates, and is delivered to the contractor either during tendering or after the award of contract. Each stage is completed prior to commencement of the next stage (see **Figure 2.8**).

The traditional sequential approach has the following disadvantages:

Figure 2.8

Fast Track Development Approach

Sequential Traditional Approach   *Fast Track Approach*
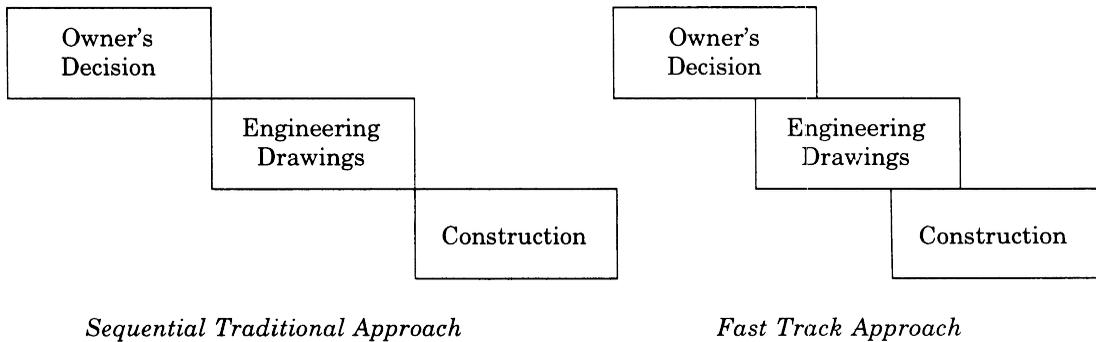
1. The owner's decision regarding the budget for building the facility is generally based on the assessment of the feasibility report without tendering the work. Thus, it lacks the input from the contractor, which may not match the budgeted cost.
2. It delays the project as the contract is finalised after the entire set of drawings and specifications are completed by the designer for the tendering bids.
3. Price to be paid by the client increases as the lowest quoted general contractor includes his mark-up both on his department executed work, as well as the sub-contractor quotation received by him. Ultimately, it is the back-to-back specialist sub-contractor who remains responsible for the quality of work and whose performance guarantee remains with the client till completion of his contract.
4. In order to secure the contract, the general contractor perceives the works to be of such quality that meets the minimum quality stipulation. Thus minimum quality and quantity attitudes result in conflicts and claims between the client and the contractor.

Traditional 'build-only' type contracts, where designs and drawings are provided by the client to the contractor, are viewed by clients as time consuming, capital intensive and risky, especially for high cost infrastructure projects. In the end, it is the owner who pays for time delays and cost of inefficiency inherited in the sequential approach.

Fast track approach.   It aims at reducing project time by overlapping project development phases. For example, in a building, foundation work can commence after its architectural and foundation drawings are ready. It need not wait till completion of all the building drawings.

The outcome of this BOT fast track total-solution infrastructure construction results in a win-win situation for the participants. The government gets the work done at a marginal cost, in less time,

and saves on specialist effort needed for high-tech projects. Builders promote their business and get a guaranteed surplus. The citizens get the needed facilities by paying a nominal toll over a fixed period of time. Thus, all the participants gain in the bargain.

Fast-track approach requires a high degree of coordination among the stakeholders and faster information processing to keep pace with the construction. It adds further complications to the al ready complex projects, but certainly makes them move faster.

2.2.7 Contracts Procurement Schedule

After the works to be contracted are decided, a contract procurement schedule is prepared. The number of construction contracts to be tendered will depend upon many factors. These include:

- Nature of the works;
- Location of the work site;
- Value of the contract;
- Availability of contractors;
- Need to accommodate local contractors;
- Need to obtain performance guarantee from a single party for a given system;
- Concern for completion at minimum cost;
- Concern for high quality;
- Current work load of the contractor and capability of the contractors;
- Time schedule of the work; and
- Political pressure.

The decision on the number and type of contracts should be carried out as a separate exercise called contract planning. At the conclusion of this exercise, a document called tender list is prepared. It is also desirable to add time dimension to the tender list and convert it into a tender schedule. The tender schedule covers only the broad scope of work; the detailed scope of work is spelt out in the tender document which is issued to the prospective contractors for bidding.

The construction contract procurement, which is a specialised field, includes the processes of issue of notice for tenders, pre-qualification of contractors, preparation of contract documents, and invitation to contractor's pre-qualification, issue of tenders to pre-qualified contractors, evaluation of bid on receipt and award of contract. The guidelines for administration of contracts and claims settlement mechanism are covered in **Appendix M**.

❑ 2.3 WORKS CONSTRUCTION METHODS STATEMENTS

2.3.1 Product Quality Management Processes

Product quality is the degree to which a set of stipulated characteristics fulfill requirements. The requirements refer to the needs or expectations of the clients/promoters, which who are stated in the approved design, drawings and specifications.

Quality yields many benefits. It reduces complaints, production costs, and production time. It improves customer satisfaction, morale of the people and the efficiency of the system. Quality

management is that aspect of overall management function which determines the quality policy, objectives and responsibilities and implements them by means such as: quality planning, quality assurance, quality control, and quality improvement. The product quality management aims to ensure that the product will satisfy the needs for which it is undertaken. In addition, a product quality management system must integrate project environment protection and workers' occupational health and safety (OH&S) management system.

In a project, the product quality management processes include: quality planning, quality assurance, quality control, quality inspection and acceptance, and quality audit (see **Figure 2.9**):

The product quality development pyramid (shown in **Figure 2.9**): links up closely with the role and responsibilities of the managers, and the quality management policy described as follows:

Figure 2.9

Product Quality Development Pyramid
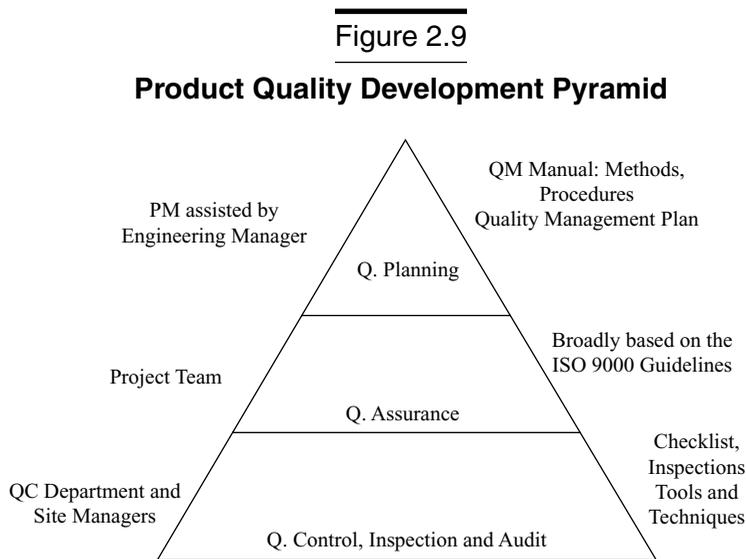
1. Quality planning aims at identifying the quality requirements and standards that are relevant to the product and documenting methods for determining, how the project will conform to these requirements and standards.
2. Quality assurance focuses on demonstrating the planned and systematic confidence building measures, to ensure that the necessary quality requirements and standards are being met in practice.
3. Quality control is the operational technique of monitoring and recording the results of execution to assess performance and make necessary changes in processes (where required) to ensure conformance to the requirements and standards.
4. Quality inspection determines the acceptability of the end product or deliverable or service or a stage of construction, to ensure that it conforms to functional requirements.
5. Quality audit is the in-house or third party's systematic and independent examination and documentation to determine whether product quality activities and related results comply with the planned arrangements and are implemented effectively to achieve project objectives.

2.3.2   Construction Methods Statement Enhances Quality and Productivity

Object of methods statement.   Construction production quality is the degree to which the production meets the requirements and methodology stated in the design and specifications. The requirements refer to the needs or expectations of the client/promoters and the methodology implies execution of construction in conformity with the approved design, drawings and specifications. A method statement describes in detail the sequence and the manner in which the work is to be executed. In order to produce a quality work, it is necessary that the methods statement is prepared by the executing agency and approved by the client engineer. Even if the contract does not stipulate preparation of method statement prior to the execution of construction work, it is still the contractor's responsibility. In order to get things right first time during construction, it is necessary that all the parties involved in construction arrive at an agreed approach with regard to the method of construction.

It is important to note that the quality must be built into the product from the early stages of the project development. An error in the design stage will have more impact on quality than, say a rework on defect rectification during production. For example, a design discrepancy in an RCC beam design:

- if noticed during pre-concreting stage will cost for redesigning and work stoppage;
- if observed after concreting will cost for dismantling and recasting; and
- if it cracks after the building is occupied then the cost of rectification will include cost of user's vacation/inconvenience and cost of rework of all the affected structural components.

Conceptually, a design defect will cost n times for design rectification prior to production, not less than n^2 times for rectification during the execution stage and for more than n^3 times for rework during the operation/maintenance stage.

2.3.3   Methods Statement Contents

The contents of a method statement will vary with the nature of activity for which the method statement is prepared. However, its format can be in tabular, descriptive text, graphs/charts or a combination of these. The contents of a post-award method statement generally include but are not limited to the following:

- Nature of work/activity with BOQ references;
- Quality compliance specifications. In particular, specifications should be as per contract and a hard copy of the contents of these specifications should be available for reference at short notice;
- Good-for-construction drawing references including shop drawings;
- Methods of construction including sequencing of work with a duration/time schedule of each operation;
- Workers' strengths to be employed, category-wise with skilled workers certification/experience (in special cases like welding, electrical work, pre-cast erection);

- Construction material to be used with sample approval references;
- The equipment to be employed with names and experience of operators and equipment calibration certificate, where applicable;
- Safety precautions to be observed and the nearby location of medical facilities;
- Materials test to be conducted after construction and the connected laboratories; and
- Name of the supervisor with qualifications and experience in similar work.

2.3.4 Benefits of Preparing Construction Method Statement

In the fast changing environment, the single most important measure for good performance is the ability to produce specified quality work.

A well-prepared method statement is bound to enhance the construction quality. Meticously implemented method statement can minimise rework of efective work, eliminate rejections and can save unwanted costs. It is a confidence building tool that satisfies the client, consultants, contractor and those executing the works. It aids the estimators and planners to refine their function. A data bank of methods statement can facilitate an organisation to develop a methods statement library for future use, when required.

❑ 2.4 PROJECT WORK SCOPE INTEGRATION PLANNING

2.4.1 Scope Integrated Plan

Project scope integration plan interlinks the scope associated features which include completion time, resources constraints, budgeted cost, risks response and their mitigation strategy, and, project management information system. This calls for the development of a project work execution plan, which integrates time, resources, costs, risks and quality specifications with the quantity of work to be performed. This integrated project work execution plan becomes the baseline for measuring the implications of scope changes and controlling the project scope performance. The subsidiary plans, which form part of the project scope integration plan include: project time, resources, cost, quality assurance, risk response plans and project management information system (see **Figure 2.1**).

Work scope management is closely linked with the achievement of project objectives. The typical Scope Integration Planning and Control-related phases and processes of a construction project are shown in **Table 2.6**.

The processes, which form part of the project scope integration plans, can be categorised as follows:

- Project time management processes;
- Project resources management processes;
- Project cost management processes;
- Product quality assurance processes;
- Risk response planning and controlling processes; and
- Project management information system for controlling integrated features.

Table 2.6

Scope Integration Planning and Control Processes

Scope Parameters	Formulation Phase	Planning and Design Phase	Execution and Control Phase	Close-up Phase
Work- scope management	Statement of project scope	Scope definition including design, specifications and BOQ	Scope verification and change control	Handing over project duly completed and acceptance with as-built drawings and related documents
Scope- time management	Strategic milestone plan	Work package time schedule	Project time control	Listing lessons learnt to improve performance of similar projects.
Scope- resources management	Main resources forecast	Resources mobilisation plan	Resources productivity control	Resources Employment record productivity norms
Scope cost management	Initial estimate	Work cost planning work cost budgeting	Cost and earned value control	Final cost estimate
Scope- risks management	Anticipated risks	Identifying and mitigating risks	Risks response control	Risks contingency amount
Scope-contracts management	Planned schedule of tenders	Contract procurement plan	Contract administration	Contract close up
Scope-quality management	Quality policy	Work quality assurance plan	Scope control re-work project	Work acceptance

2.4.2 Project Time Management Processes

In construction, all projects are time bound. The project time objective specifies the project completion time. Time is the essence of all construction projects. Time delays attract penalties while early completion can earn rewards. However, in spite of one's best efforts to complete a project on time, changes from the original estimated project time plan sometimes do occur.

A plan, prepared well before the commencement of construction on a project, can be instrumental in formulating directions, coordinating functions, setting targets, forecasting resources, budgeting costs, controlling performance and motivating people. It is for this reason that after the scope is defined, the project planning starts with time planning as the first step.

Project time management processes, the related tools and techniques employed and the outcome of each process are reflected in the model shown in **Table 2.7**. It is illustrated in subsequent sections with Exhibits from live projects.

1. Identifying Activities Using Project Work Breakdown Structure Techniques. The project activities identification technique depends upon the nature of the project. Some illustrations are given follows:

Table 2.7

Project Time Management Model

Processes	Tools and Techniques	Outcome
Identifying project activities	Project work breakdown techniques	Activity list
Estimating activity duration and resources	One-time estimation; three-time estimation; probabilistic estimation; activity resources estimation	Activity duration; activity resources database
Networking activities	Project network analysis time-cost trade-off	Project completion time; critical activities; time-cost functions
Developing project schedule	Bar chart for simple project	Project time schedules; activity database
	Network-based schedules for complex projects	
	Line-of-balance (LOB) chart for repetitive projects	
Controlling project schedule	Monitoring methodology	Updated networks and schedules

Nature of Project	2000 Housing Units Project Exhibit References
Simple projects	Exhibit 3.4 Section
Complex projects	Exhibits 3.1 to 3.3 Section
Simple repetitive projects	Exhibit 3.5 Section
Complex repetitive projects	Exhibits 3.6 and 3.7 Section

The project activities identification techniques are covered in **Chapter 3**.

2. Activities Duration Estimation.   Duration of an activity is defined as the expected economical transaction time. The estimation of this time is based upon the current practices, carried out in an organised manner, under normal prevailing conditions and the person responsible for the activity's performance preferably must do its assessment. Activity duration estimation is the method to determine the time period and the connected resources needed to complete individual activities. The activity duration estimation methodology using one-time and three-time is covered in **Chapter 3**.

3. Project Network Modeling and Analysing Techniques.   Project activities modeling methods depict the logical sequencing of activities using standard symbols and conventions. These models are time analysed to identify the critical path and for computing the project completion time.

Some illustrations from 2000 Housing Unit Project using CPM, PERT and Precedence networks Techniques are as follows:

- CPM Network of Pumping Station Project—**Exhibit 4.1**;
- PERT Network of Pumping Station Project—**Exhibit 4.3**;
- Precedence Network of four foundations rafts constructed—**Exhibit 5.2**;
- Summary Precedence Network of Primary School—**Exhibit 5.4**;
- Precedence Network of a group of similar Education Buildings—**Exhibit 5.5**; and
- Precedence Network of Raw Water Clarifier Tank—**Exhibit 5.7**

The Project Network techniques used for planning projects are covered in **Chapters 4** and **5**.

4. Time Scheduling of Work.   Scheduling means putting the plan on a calendar time scale. The scheduling methodology varies with the planning technique and the nature of the task. Simple projects can be scheduled using the bar chart methodology. Line-of-Balance (LOB) technique is widely accepted for scheduling repetitive works projects. Network scheduling methodology is suitable for all types of projects. There are many other scheduling techniques. Each technique has its merits and demerits. Generally, all scheduling techniques use a time scale along horizontal axis. The time scale for most of the schedules uses 'days' as the unit of time because it can cater to non-working days. Schedules are best presented in the bar chart form for ease of comprehension and communication.

The scheduling methodology depending upon the type of project can be broadly divided into two categories:

- Scheduling non-repetitive network based projects; and
- Scheduling repetitive projects using line of balance techniques.

Some of the illustrations from 2000 Housing Units Project are given in the following Exhibits:

- Time limited Site Development Project—**Exhibit 6.4**;
- Resource limited Site Development Project—**Exhibit 6.5**;
- Manpower optimised education building Projects—**Exhibit 6.6**;
- Residential Building Finishes Plan: Derived Using LOB Technique—**Exhibit 6.7**; and
- Residential Building Monthly Target—**Exhibit 6.10**.

The time schedule of work serves many purposes: it simplifies the project time plan by putting it on a calendar basis; it verifies fulfillment of time objectives; it aids in optimising resources; it evaluates implications of resources constraints, and; it enables forecasting of input resources, expenditure and income. These resource forecasts cover manpower, materials, machinery, work done-income and cash-flow. The Project Time Scheduling techniques are covered in **Chapter 6**.

5. Time Schedule Controlling Techniques.   A project plan indicates the path to achieve the project objectives. During the implementation stage, the Project Control System aims at ensuring

the execution of work as per the planned schedule and by the application of corrective measures, including re-planning when necessary, in order to achieve the project objectives. Some illustrations from 2000 Housing Units Project given in the book are as follows:

- Primary School Construction: Updated Summary Precedence Network—**Exhibit 16.1**;
- Updated Line-of-Balance Chart—**Exhibit 16.2**;
- Updated Bar Chart Schedules—**Exhibit 16.3**; and
- Pumping Station Project Original and Time Compressed Network—**Exhibit 16.6**.

The Project Time schedules controlling techniques are covered in **Chapter 16**.

6. Illustration. The bar-chart skeleton Time Schedule of the Residential Building of 2000 Housing Units Project is shown in **Exhibit 2.2**. It looks simple, but its development requires in-depth skills in project plan development techniques covered in the **Chapter 6** of this book.

Some illustrations of development processes of time schedules from 2000 Housing Units Project and other projects are given in **Chapters 3–6**. These are also shown in List of Illustrations.

7. Project Management Software. Those readers familiar with project management software like MS Project and Primavera products, can develop the network and schedule directly on the computer screen and monitor the time schedule, provided they have worked out the inputs such as project calendar, activities involved, duration estimate, and the network logic. The capabilities of these software are outlined in **Appendix F**.

2.4.3   Project Resources Management Processes

Project resources management. It aims at planning, scheduling, procurement and control of manpower, materials and equipment required for the project. A model showing resources processes, tools and techniques used for processing and the outcome in each case is outlined in **Table 2.8**:

Table 2.8

The Project Resources Management Model

Resources processes	Tools and technique	Output
Manpower planning	Manpower forecasting and scheduling technique	Manpower requirement and mobilisation plan
	Manpower organising methodology	Project task force organisation
Materials planning	Identifying and processing the materials required.	Material procurement plan
	Designing materials inventory	Inventory management plan
Equipment planning	Analysing equipment requirement	Equipment requirement list
	Equipment selection criteria	Equipment procurement plan
Resources productivity control	Resources productivity analysis	Resources productivity improvement and trends

Exhibit 2.2

2000 Housing Units Projects: Summary Schedule of Construction Tasks

No.	Work Description	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov
	Residential Buildings																			
1	Foundation																			
2	Precast Reaction																			
3	Finishes																			
	Education and Public Buildings																			
4	Foundation																			
5	Superstructure																			
6	Finishes																			
	Externeral Utility Services																			
7	Sewage and Strom Water Drains																			
8	Receiveing and Substations																			
9	Sewage and Storage Water Pump Houses																			
10	Gas Supply																			
11	Electric Supply																			
12	Road and Parking Areas																			
13	Landscaping and Sports Field																			

Months	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov
Working Days in a Month	25	24	25	25	24	25	24	24	22	20	24	25	24	25	24	25	24	25	24
Working Days Cumulative	25	49	74	99	123	148	172	196	218	238	261	285	310	334	359	408	433	457	503

Months (cont.)	Feb	Mar	Apr	May	June	Jul	Aug	Sep	Oct	Nov
Working Days in a Month	23	23	23	24	25	24	25	24	25	24
Working Days Cumulative	503	546	569	594	618	643	668	692	717	741

Planning construction manpower. Project manpower plan primarily focuses on: determining the size of the project workforce, structuring the project work force into functional groups and worker teams, and scheduling manpower employment to match with the task requirement. Project construction workers scheduling process involves:

- Identifying the tradesmen or the skills required.
- Establishing productivity standards to determine the number of workers needed to perform a given job in a specified time.
- Forecasting date-wise workers requirement for accomplishing the project work.
- Organising the planned work force into operating work teams, which have been assigned programmed tasks.

These above aspects of manpower planning are covered in **Chapter 7** and **Appendix G**. The construction Workers' Monthly Requirement Forecast for 2000 Housing Units Project is shown in **Exhibits 2.3.**

Planning construction materials.   The materials planning and programming, which is the key function of materials management, is closely linked with project planning and control set-up. Both these work together to classify materials activity-wise, cost-wise and develop a plan for procuring and stocking construction materials, so as to provide materials of the right quality, in the right quantity, at the right price, from the right source and at the right time.

Construction materials procurement schedule involves the following processes:

- Identifying the materials required;
- Estimating quantities and defining specifications;
- Forecasting requirements;
- Locating sources for procurement;
- Getting materials' samples approved; and
- Designing materials' inventory and developing a procurement plan, to ensure the flow of materials till the connected construction works are completed at the project site.

The aforementioned aspects of materials planning are covered in **Chapter 8**. The list of Residential Building's main materials of Direct Material of the 2000 Housing Units Project is shown in **Exhibits 2.4.**

Planning and selecting construction equipment.   Construction equipment helps to produce a given output at an accelerated speed in a limited time. Equipment saves manpower, which is becoming more costly and more demanding day by day. Equipment adds a sense of urgency and improves productivity, quality and safety. Although equipment involves an initial heavy investment, on the whole it adds to the profitability by reducing overall costs, provided it is properly planned, economically procured and effectively managed.

Production tasks which can be performed with the equipment include: excavating, handling, transporting, filling, compacting, grading, hoisting, concreting, precasting, plastering, finishing,

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Exhibit 2.3

2000 Housing Units Project Extract from Workers' Requirement for Crash Programme

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No.	Work Description	May	Jun	Jul	Aug	Sep	Oct	Next Sep
1.	**Construction Works**							
	Carpentry Work							
	Furniture carpenter							56
	Wood polisher							3
	Shuttering carpenter	41	77	122	124	124	124	76
	Carpenters' helper	10	38	60	60	60	60	90
	Masonry Work							
	Concrete mason	10	46	46	46	48	58	112
	Block work and plaster mason	14	14	14	15	47	78	41
	Tiling mason						12	104
	Masons' helper	30	40	40	40	40	40	272
	RCC Steel Work							
	Rebar fabricator	22	45	74	91	99	104	109
	Rebar helper	20	22	36	40	40	44	67
	Painting Work							
	Painter	1	2	2	2	2	2	20
	Painters' helper		2	2	2	2	2	20
	Electrical Works							
	Electrician	10	16	16	16	18	27	77
	Electrical helper		1	5	5	15	24	90
	Plumbing and Sanitary Works							
	Plumber/Pipe fitter	3	10	10	34	56	68	47
	Plumbers' helper	1	10	10	34	50	59	53
	Unskilled Work							
	General helpers	70	70	124	142	164	204	211
2.	**Mechanical Trades**							
	Light vehicle drivers	7	15	15	15	15	15	23
	Heavy vehicle drivers	9	20	20	20	20	20	38
	Equipment operators	1	18	38	55	57	59	94
	Blacksmith	1	12	12	12	12	12	43
	Welder	5	12	12	12	12	12	15
	Sheet fabricator						18	26
	Auto electrician	1	2	2	2	2	2	5

Mechanic diesel/ petrol	6	8	10	10	10	10	16
Mechanic operator/ helper	1	8	30	41	46	48	13
Riggers	27	36	36	36	36	36	97
Other categories	3	3	3	28	28	28	36
Administration Staff							
Cook	4	10	10	10	10	10	24
Mess helper	1	26	26	26	26	26	10
Security staff		6	6	6	6	6	10
3. **Administration helper**	5	11	11	11	11	11	44
Total	303	580	792	896	953	1118	1942

trenching, cable-laying, pipe-laying and so on. In addition, the supporting equipment at the project site consists of generators, transmission lines, pumping sets, treatment plants and other utility services equipment. Equipment planning and selection processes aim at:

- Identifying construction tasks to be undertaken by mechanical equipment;
- Assessing equipment required;
- Exploring equipment procurement options; and
- Participating in decision-making for selecting the equipment.

Equipment planning and selection processes in a project, are covered in **Chapters 9** and **10**. Major construction plant and equipment employed in 2000 Housing Units Project is tabulated in **Exhibits 2.5.**

Forecasting resources input and output. A resource plan shows when and in what quantity the resources are to be inducted at the project site to achieve the project targets. The resource planning focus is to determine what resources (workers, materials, equipment), in what quantities and quality, and when and where each is be provided to perform project activities. The basis of forecasting is the schedule of work.

Resource forecasts are generally depicted graphically with time represented along the abscissa and the resources along the ordinate axis, to determine the data-wise and cumulative requirement pattern. The resulting graphical pattern for most of the cumulative forecasts is an 'S' shaped curve. These curves show the cumulative forecast of the value of work done and manpower requirements. **Exhibit 2.6** shows the forecast of manpower required and the value of work done in 2000 Housing Units Project. The methodology for forecasting input resources and earned value output is dealt with in **Chapters 6** and **12**.

Resources productivity. The success of a project depends upon the performance of the input resources. Productivity provides the scale to measure the performance of these input resources. In general, productivity is defined as the ratio of output to input. There are various methods for determining resources productivity. It can be measured as under:

Exhibit 2.4.

Main Materials Required: Residential Buildings with Precast Concrete Super Structure Project.

S. No.		Item and Description	% Building Materials Total Amount
I		**Bulk Materials**	
	1.	Cement	19.43
	2.	Sand	6.39
	3.	Aggregate	5.75
	4.	Admixtures	4.80
	5.	Steel	15.22
	6.	Weld mesh	0.48
	7.	Binding wire	0.26
	8.	Bitumen	0.12
	9.	Anti-termite chemicals	0.50
	10.	Polythene sheets	0.36
	11.	Imported soil	0.93
	12.	Softwood	0.42
II		**Wiring**	
	13.	PVC conduits and accessories	0.33
	14.	Socket outlets	0.32
	15.	Armored cable	0.39
III		**Screed**	
		Cement	Included in No. 1
		Sand	Included in No. 2
IV		**GRC Panels**	
	16.	GRC panels	6.25
V		**PVC Plumbing**	
	17.	PVC Pipes and accessories	2.64
VI		**GI Plumbing**	
	18.	GI pipes and fittings	0.56
	19.	15 mm valves	0.26
	20.	Hot water pipe	0.29
VII		**A/C Ducting**	
	21.	GI Sheet 24 g	0.43
	22.	GI Sheet 22 g	0.39
VIII		**Staircase Metal Works**	

	23.	40 mm GI pipe	0.32
IX	**False Ceiling**		
		Softwood	Included in No. 12 above
	24.	Asbestos sheet	0.36
X	Ceramic/Glazed tiles		
	25.	Tiles Type A	0.52
	26.	Tiles Type B	0.42
	27.	Tiles Type C	0.63
	28.	Tiles Type D	2.50
XI	**Doors/Windows including shuttering/Glazing**		
		Softwood	Included in No. 14
	29.	Door/windows profiles	1.99
XII	**Sanitary fittings**		
	30.	European water closet	0.22
	31.	Bidet	0.20
XIII	**Painting**		
	32.	Spray plaster	1.31
	33.	Plastic emulsion paint	0.71
	34.	Paint primer	0.46
	35.	Paint putty	1.09
XIV	**Electrical Fittings**		
	36.	Electrical holder and fittings	1.56
XV	**Kitchen cabinets/Wardrobe**		
	37.	Kitchen cabinets	2.92
	38.	Wardrobe	3.21
XVI	**PVC Tiles**		
	39.	PVC tiles	1.28
	40.	PVC skirting	1.16
XVII	**PVC Handrail**		
	41.	PVC handrail	0.02
XVIII	**Roof Treatment**		
	42.	Roofing felt	2.50
	43.	Bitumen primer	0.46
XIX	**External Finishes and Miscellaneous Items**		
	44.	Waterproofing compound	0.72

Worker's productivity	=	Quantity of work done per man-hour
	=	Work units/Effort in man-hours
Material productivity	=	Quantity of work done per unit of materials

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Exhibit 2.5

2000 Housing Units Project: Major Plant and Equipment Planned

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Category	Quantity	Category	Quantity
I. Earthmoving and Road Making Machinery		**V. Power Generation and Water Supply Machinery**	
(1) Dozers	2 Nos	(1) Generators – 500 KVA	11 Nos
(2) Loaders shovels	7	(2) Generators – 175 KVA	10
(3) Excavators	3	(3) Generators – 25 to 55 KVA	6
(4) Compressors	8	(4) Pumps	7
(5) Road rollers—Vibratory and pneumatic	2		
(6) Motor grader	1	**VI. Precast Factory Machinery**	
(7) Asphalt hot mix plant	1	(1) Batching plant 100 cu m/hr	1
(8) Asphalt paver	1	(2) Gantry cranes	10
(9) Tar boiler	1	(3) Steam boilers	2
(10) Bitumen sprayer	1	(4) Mould—vibratory	75
(11) Soil compactors	30	(5) Electric cars	4
		(6) Prime movers for trailers	5
II. Concreting Machinery		(7) A frame trailers	10
(1) Batching plants 35 cu m	2	(8) Flat head trailers	5
(2) Transit mixers 6 cm	4		
(3) Concrete pump	1	**VII. Manufacturing and Fabrication Workshop**	
(4) Concrete mixers 21/4	3	(1) Duct making machines	10
(5) Screed pumps	4	(2) Inserts manufacturing machines	20
(6) Mobile conveyors	4	(3) Metal work fabrication machines	7
		(4) GRC manufacturing machines	9
III. Erection and Handling Machinery		(5) Plastic mounding machines	2
(1) Crane 55 tons	4	(6) Wood work and carpentry machines	15
(2) Crane 20 to 35 tons	4	(7) Steel doors and windows manufacturing machines	13
(3) Crane 6 to 10 tons	3	(8) Rebar fabrication machines	8
(4) Forklifts	12	(9) Block making machine: 2000 blocks/hr	1
IV. Transport Fleet		(10) Spraying and plastering machines	6
(1) Heavy duty tractors/tippers/dumpers/ tankers	35		
(2) Dumpers (2 ton capacity)	16		
(3) Farm tractors with trailers 81 HP	5		

$$\text{Equipment productivity} \quad \begin{cases} = \text{Work unit's performed/Material quantity} \\ = \text{Quantity of work done per equipment hour} \\ = \text{Work units/Effort in equipment hours} \end{cases}$$

Overall productivity   = Value of work done/Cost of work done

Productivity control aims at ensuring an efficient utilisation of the inputs of man, materials and sequipment to produce specified quality of work. Efficient utilisation of resources at the project site is accomplished by identifying the causes of their wastage and by effecting improvements so as to minimise this wastage. The causes of wastage are located by analysing the variances:

Exibit 2.6

2000 Housing Units Project
Man-month Requirement and Earned Value Forecasts

Comulative in million

Time in Months
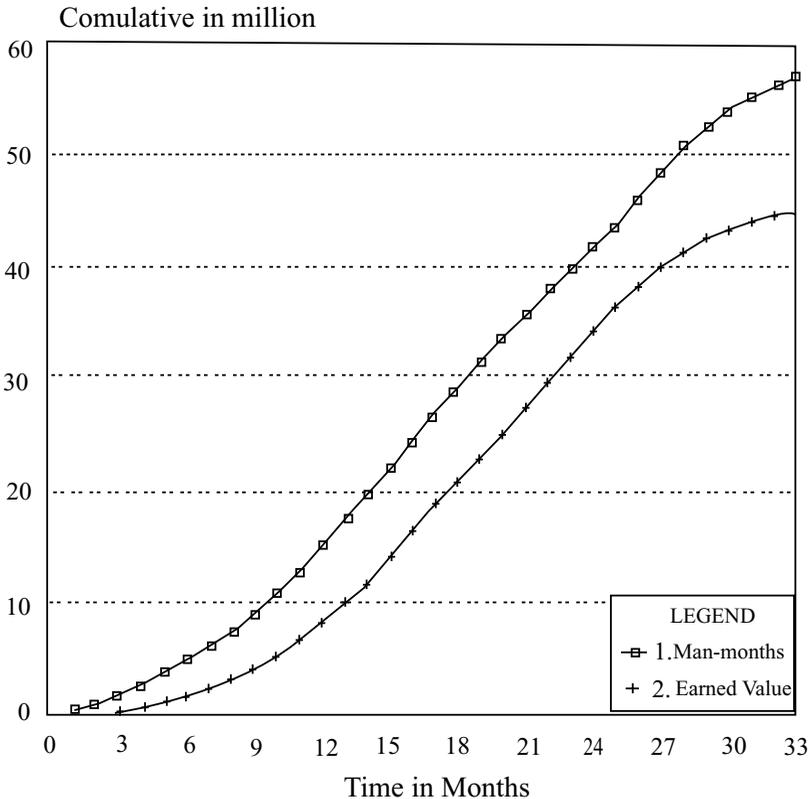
1. Represent forecast in thousand man-month
2. Show value of work done in million dinar, 1 Dinar = $ 3.2

Productivity performance variance = Planned productivity – Actual productivity

$$\text{Productivity performance index} = \frac{\text{Planned productivity}}{\text{Actual productivity}}$$

Labour, equipment and material productivity needs to be controlled in construction projects. These and the connected functions of Construction Project Manager are described in **Chapter 14**.

2.4.4 Project Cost Management Processes

The Project Cost Management System includes the processes relating to planning costs baseline for each work package, budgeting work package, controlling cost by analysing direct and budgeted costs behaviour, predicting trends and forecasting cost-at-completion. These processes are

interdependent and do overlap. However, they are described here as distinct processes because the tools and techniques for each are different (see **Table 2.9**).

Table 2.9

Project Cost Management System

Processes	Tools and Techniques	Outputs
Estimating cost	Cost estimation method	Revised cost estimates
Planning cost	Cost breakdown structure: work–cost breakdown structure	Work package standard cost baseline. Work package budgeted cost (earned value) baseline
Budgeting cost	Budgeting cost methodology	Project budget allocations; Cost management plan
Controlling cost	Direct cost control technique. Budgeted cost control (EV) technique	Revised cost estimates and/or revised project budget. Cost-at-completion forecast

Estimating costs.   Cost estimation is a specialised field. It starts with project need identification and continues till the project close-in time. The cost estimation methodology is outlined in **Chapter 11**.

Planning construction standard costs.   The construction cost plan covers engineering practices that integrate estimating, planning judgment, costing techniques and accounting discipline for developing standard costs. It enables the preparation of financial forecasts, the project budget and cost control measures with the ultimate goal of achieving project profit/cost objectives. Cost plan uses the standard cost concept for costing work-packages, work-items or activities. The standard cost technique is widely applied in forecasting, budgeting, accounting and controlling costs. The cost planning estimation methodology is outlined in **Chapter 11**. Direct labour and direct material standard costs estimated for the foundation work package of the 2000 Housing Units Project (data modified) are listed in the illustrations given below:

1. **Exhibit 3.11** shows the foundation construction sub-project: activity-wise workers' requirement and cost estimation for one foundation module construction.
2. **Exhibit 3.12** illustrates the foundation construction sub-project: major materials requirement estimate for one foundation module.
3. **Exhibit 10.2** demonstrates construction equipment costing: hourly owning and operating cost estimate.

Planning construction budget.   A project budget reflects the financial plan of operations, with specified goals and the costs expected to be incurred for achieving these goals. The primary

purpose of having a budget is to assign financial targets and resources to each functional group, so as to establish a basis for controlling their performance. It also helps to make site executives work with cost-consciousness instead of purposeless routine working.

The basis of a budget is the project plan and its schedule of work. The preparation of a budget involves structuring of the project's functional organisation into Production, Services and Administration responsibility centres. Each responsibility centre is assigned its goals in the form of a work done budget and production targets and is allocated resources necessary to achieve the assigned goals. Finally, a project financial plan is compiled in the form of a Project Master Budget. These aspects and the methodology for preparing the project construction budget are covered in **Chapter 12**.

Costs and earned value control.   Cost control is the restraining of expenditure within the predetermined limits. It involves the processing of reports received from various responsibility centres or operating divisions, relating the cost incurred with the set standards, analysing the reason for any variances and presenting the results to the project management for decision making and initiating remedial measures.

The cost and performance control process follows an active and forward-looking approach. It does not confuse itself with the historical data contained in cost reports and accounting documents, but goes further to indicate corrective measures so as to minimise inefficiencies and reduce costs. In fact, no project management can be effective without first installing and operating an effective cost control system. **Chapter 15** describes the methodology for exercising project cost and performance control by the project monitoring team and for controlling the direct costs, contribution and the budgeted costs, and the earned value management technique. It also outlines the responsibility for controlling costs and the approach needed to minimise them.

2.4.5   Risk Response Planning and Controlling Processes

Business decisions are based on future predictions about the environment. In the early days of project management, the projects were generally of short duration, about one to three years, and the environment was much more stable. The modern day projects, such as privatised infrastructure BOT projects, have a project life that is spread over many years. With market globalisation, projects are becoming larger and more complex. These projects involve a large capital outlay, generate unbalanced cash flows, and involve complex contractual arrangements. They encounter changing economic and financial situations, face unstable political climate resulting in changing regulatory issues and have to cater to unpredictable environmental changes. The stability of modern projects is thus, constantly subjected to certain sensitive and volatile, external and internal environments. The resulting instability causes uncertainty. Uncertainties bring with them, elements of risk. The success or failure of a project largely depends upon the effectiveness and the efficiency with which the risks and uncertainties are managed. In fact, risk management has emerged, as the main function of project management.

Project risk management is the art and science of managing risks caused by unforeseen changes (uncertainties) which may require deviations from the planned approach and may therefore affect

the achievement of the project objectives. It involves systematically identifying, analysing, planning and controlling risks. It provides greater insight into risks and their impacts for taking risk related decision.

The risk identification process.   It involves researching the project to determine the sources of risk, and connected potential risk factors that lead to risk events and thereby reducing the chances of overlooking any potential risk event.

Risk analysis or risk assessment process.   It aims at quantifying risk exposures to enable mitigation and development of project risk response plans for managing risks during the execution of the project. Quantifying risks involves the estimation of the probability of occurrence and the cost of risk consequences of each risk element. This is followed by the ranking of risks.

The risk response plan development process.   It considers risk transfer, reduction, avoidance and other mitigation tools to develop a risk response plan to ensure that the appropriate risk warning tools are in place, to handle risks efficiently. A pre-determined risk response plan can minimise the consequence of possible adverse future events and can maximise the benefits of positive future events.

Risk control process.   It aims at controlling deviations to cut down risks and maximise the project value. It handles risks in a manner that achieves project objectives efficiently and effectively, by monitoring and adjusting plans and evolving alternate plans to manage foreseeable risks, whenever necessary.

Table 2.10

Project Risk Management Models

Processes	Tools and Techniques	Outcome
Risk Identification	Work breakdown analysis Management process analysis System flow analysis Brain storming Check-list templates Knowledge experts judgement	Sources of risks Potential risk events Project risks checklist
Risk Analysis	Risk probability assessment Risk impact assessment Risk classification Risk ranking	Time-overrun risk assessment Risk contingency assessment Risk assessment Sensitivity List
Risk Response Planning	Risk mitigation planning (or strategy)	Risk response strategy Risk response plan/baseline Responsibilities allocation
Risk Response Control	Risk monitoring methodology	Risk-related corrective action

2.4.6 **Project Management Information System**

Information is at the root of the decision-making process. It links time, cost and resources performances to achieve the ultimate project objective of total quality management. Information plays an important role in binding the building blocks of modern multi-division, multi-location and multi-national organisations.

Project performance monitoring follows a systems approach. Each organisational unit in a project usually referred to as a responsibility centre, can be viewed as a sub-system. These subsystems are interdependent and interactive. **Figure 2.10** shows the outline of the control system of a housing units project.

Figure 2.10

Project Control System

Project Control System
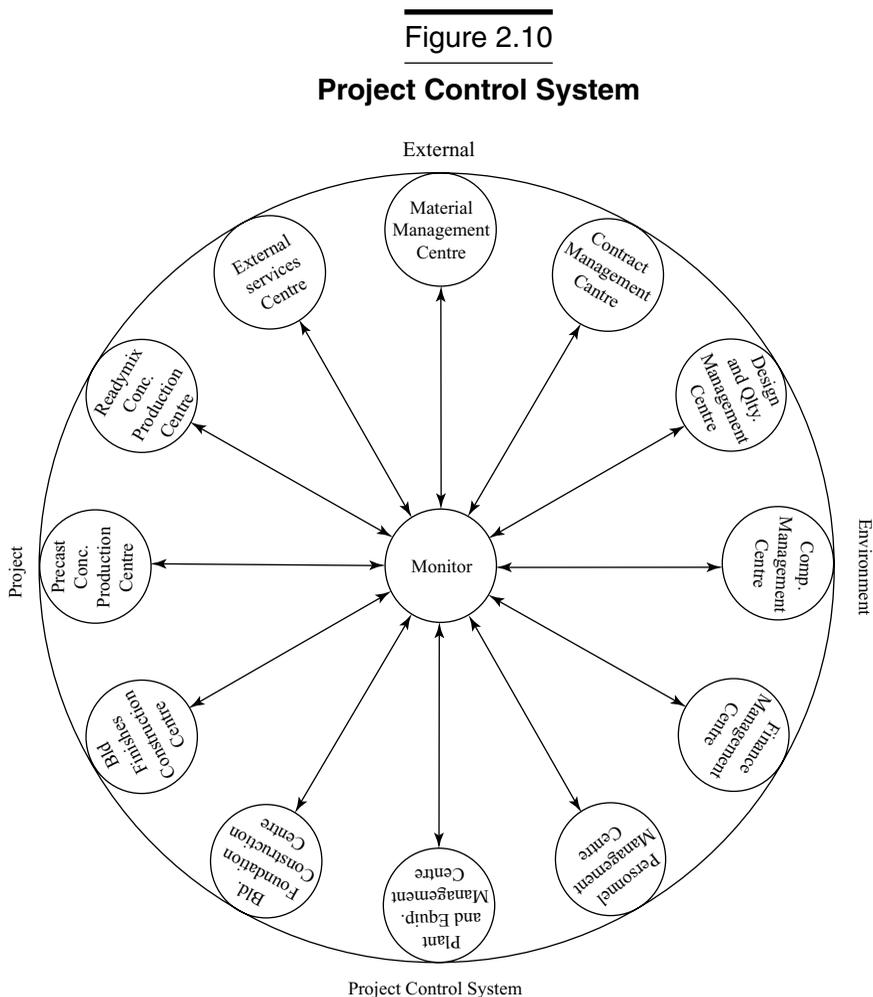
The performance inputs generate a considerable amount of tabulated data. This data is generally unorganised. In order to comprehend the actual status, these reported inputs need to be properly

sorted out, by making and updating suitable displays depicting the current performance status and the extent of deviations from the planned path.

The project monitor, who manages the Project Management Information System (PMIS), is assigned the task of planning data tapping, data consolidation, performance analysis, trend forecasting, data recordkeeping, data processing, timely communication of the performance feedback to the project teams and the information reported to the top management. Consolidated data displays in the form of graphs, charts, diagrams, tables and pictures have an eye appeal. They are the best means of human communication. Visual displays help in understanding the complication and interrelated state of performance of various control centres at a glance and provide an insight into the operations.

Planning, executing, accounting, monitoring, analysing information, communicating, decision-making, and re-planning (when necessary), is a continuous controlling process. It goes on until the completion of the project. The modes of information communication by the monitor to the project teams and the top management is covered in **Chapter 18**.

2.4.7   **Project Integrated Control Methodology**

Baseline plans controlling methodology. In a typical project, control focus is on methodology for controlling the baselines of scope, time, resources and cost objectives. These are covered in chapters **Chapters 13–17** as shown in **Table 2.11**.

Table 2.11

Nature of Performance Baselines Controlling Scope, Resources, Cost, Times, and Risks

S. No	Goals Control Parameters	Baselines	Control Methodology
1	Project control frame work	-	See Chapter 13
2	Project work scope control	Work scope definition	See Chapter 13
3	Resources productivity control	Resources performance standards	See Chapter 14
4.	Cost and earned value Control	Planned and budgeted costs	See Chapter 15
5.	Time schedule control	Project master-time schedule	See Chapter 16
6	Risks during project implementation.	Resources response plan	See Chapter 17

Milestone plans.   These are the goal achievement targets of the key events set in the baseline plans. These key events can either be the delivery date of an important stage of a deliverable or the date of receipt/accomplishment of an important event. Some of the examples of milestones in a medium size and built-only repetitive building construction contract project are:

- Date of handing/taking over of the site;
- The scheduled dates for approval of method statement;
- Date of submission of RCC materials with test reports;
- The scheduled dates for approval of samples of RCC and finish materials;
- Date of completion of foundation, superstructure and finishes of each building;
- Date of completion of key events of external utility services, item-wise; and
- Date of handing over of the completed project.

It is an accepted practice to list the milestones on top of the chart depicting Project Time Schedule. In addition, a separate Summary Network Milestones Chart can facilitate better sequencing of these key events.

Responsibility assignment matrix (RAM) chart.   RAM shows the responsibility and accountability, assigned to the concerned managers in an overall plan for the accomplishment of a given task. The traditional organisational chart outlines the basic relationships and the grouping of positions with the formal channel of authority and responsibility. But it does not show how individual functions are related to each other in the organisation environment. In addition to the traditional organisational chart, organisations do require another chart commonly called the responsibility assignment matrix (RAM) or the linear organisation chart, to define the involvement of the stakeholders in the project activities.

The RAM specifies individual and collective roles and authority relationship with overlapping involvement (as applicable) in the organisation of line managers, staff and stakeholders. It can include time, responsibility and accountability of each member during various phases of the project. It can be developed to explain the procedure for designing, developing and operating of the organisational interface.

The RAM also indicates as to when an individual's role may be reviewed or when he may sign off from a phase, if not required. The RAM can be drawn to depict the following:

- To pin-point the organisational position and functional interface between the members and to support the organisational goals, usually defined in terms of milestones to be achieved;
- To specify the individual and collective roles and authority relationship with overlapping involvement and commitment (as applicable) in the organisation of line managers, staff and stakeholders; and
- To assign responsibilities in developing systems, procedures and operating functions of the organisational interface.
- To update the individual' role and the related status.

The RAM is a very useful tool for managers and stakeholders in the project environment to understand the functions and their authority relationships. For a simple project, these relationships can be shown easily but for a complex project, a series of descending charts for various interacting levels and different symbols may be necessary. This will ensure that there is no uncertainty in an individual's mind about his role in each phase of the project and that he has a clear idea when he finally reverts to his parent department.

To quote an example, the project plan preparation is not a one-man show, it needs team effort. Although the project chief planner is accountable for developing the plan, others also share responsibility along with him. A typical responsibility matrix for evolving a construction plan is shown in **Figure 2.11**.

As can be seen from **Figure 2.11**, the plan development proceeds stage-by-stage. It involves participation and acceptance of a commitment by the various functional heads, especially the executive director, the project manager and the construction managers. Initially, only the project conceptual/preliminary plan is made, it is subsequently supplemented when the project work unfolds and the execution methodology is finalised. Obviously, all this needs a highly skillful, matured and experienced chief planner, who can win over the cooperation and control the project team during the planning phase of the project.

Figure 2.12 shows another example of a RAM chart of development of Design and Drawings of Education Building and External Services of 2000 Housing Units Project. The development of such a chart, combined with the discussions that usually accompany such a development, can help greatly to facilitate an understanding of the functions of the project design and plan development team.

❑ 2.5 ROLE AND FUNCTIONS OF CHIEF PLANNER

2.5.1 Role of the Chief Planner

The project environment often tends to create a conflict among the project executives. At times, there may be a lack of mutual trust between them, especially when they dislike following a certain plan or when someone monitors their performance. Non-cooperation is also not uncommon. Occasionally, people may render incorrect data to mislead the planners or to cover up their unsatisfactory performance.

Instances are also not lacking where a conflict may develope due to some inappropriate behaviour pattern of the project planning cell itself, a situation which must be avoided at all costs by the chief planner. The smoothening of planning functions can be achieved to a large extent if the chief planner plays effectively the following key roles.

*Service role***.** The planning chief primarily performs a service function: he exists to render assistance to the executives and staff in the performance of their planning and control function. He maintains close liaisons with the heads of various departments including: site supervisors, project engineers, designers, estimators, quantity surveyors, material purchasers, accountants, personnel administrators, plant and machinery controllers and all the other managers in the project. He participates in almost all the meetings, discussions and decision-making exercises so as to assist the project manager in performing his planning functions.

*Information record-keeper role***.** The planning chief is the manager of the project data bank. He maintains the project information bureau. He runs the project information service, both for internal and external needs. He should be able to process data, produce and advertise information

Figure 2.11

Format for Development of Project Preliminary Plan Responsibility Assignment Matrix

Project Responsibility Chart

A—Approval in principle
C—Coordination
D—Development
F—Finalisation
I—Information to concerned managers

Project: Housing Units Build-only
Project Contractor's Preliminary
Construction Plan Development

Planning Processes	Serial No.	Contractor's Managers' Responsibilities								
		Project Manager	Construction Manager	Planning Manager	Technical Manager	Quantity Surveyor	Material Manager	Equipment Manager	Adm Manager	Finance Manager
Formulating planning assumptions	1									
Developing construction methods	2									
Listing work packages	3									
Identifying activities	4									
Estimating quantity of work activity-wise	5									
Developing sub-networks	6									
Developing preliminary time plan	7									
Scheduling drawings requirements	8									
Estimating materials	9									
Scheduling work to be sub-contracted	10									
Forecasting month-wise:	11									
Workers requirements	(a)									
Shuttering movement and requirement	(b)									
Concrete requirement forecast	(c)									
Imported materials schedule	(d)									
Equipment and vehicles needed	(e)									
Site staff requirement	(f)									
Work done inflow	(g)									
Production costs	(h)									
Designing site organisation	12									
Materials samples approval programme	13									
Developing resources mobilisation plan	14									
Preparing project preliminary budget	15									
Designing PMIS	16									
Developing quality assurance system	17									
Local materials testing schedule	18									

Scheduled Working Days.

Figure 2.12

Development of Design and Drawings of Education Buildings

Project Responsibility Chart

Project: 2000 Housing Units Project: Design and Drawings Development of Education Buildings and External Services

Period : Week No. (Starting 14/5)

Legend:
- A—Approves
- R—Recommends
- I—Information
- S—Submission to Client
- C—Consultation

Principle/Milestone name	Site Execution Date/Month	Client Manager	Architect	Structural Designer	System Designer	Line Manager
Master Plan						
Coordinates education buildings	1/8	A	R	S		I
Alignment walkways footpaths and car parks		A	R	S		I
Coordinates utility services		A	R		S	I
Corridor (Services building)		A	S			I
Primary and High Schools buildings						
Final architectural drawings		A	S			I
Foundation	1/8	A		S		I
System design		A			S	I
• Structural		A	R	S		I
• Electrical		A	R		S	I
• Plumbing and Sanitary		A	R		S	I
• HVAC		A	R		S	I
Working drawings						
• Architectural drawings	1/10	A	S	S		C
• Structural	21/11	A	R	S	S	C
• Electrical	21/11	A	R		S	C
• Plumbing and sanitary	21/11	A	R		S	C
• HVAC	30/11	A	R		S	C

Week No. (Starting 14/5): 1 2 3 4 5 6 7 8 9 10 11 12 13

and provide it to the information seekers. In this information marketing role, the planning cell is expected to maintain up-to-date displays and records of the following:

- Contract documents including contract conditions, drawings, specifications, bill of quantities, and activity-wise cost breakdown;
- Project models, pictures, charts and tabulated data to illustrate the layout, scope and progress of the work;
- Project plans and planning assumptions including the planning data and output norms;
- Statistics of all reports and returns handled in the project and their pictorial displays;
- Records of minutes of all meetings and conferences, policies and important correspondence;
- Control charts showing progress of work, resource availability, cost status and anticipated trends; and
- Revised unit rates and resource planning data for each item of work, for reference in future projects.

Coordination role.   Coordination is one of the most sensitive function of the management. It aims at an effective harmonisation of the planned efforts for accomplishing the goals. If the situation variables are measurable, the policies and the procedures well-defined, and communication flows smoothly in all directions, then esprit de corps prevails and everyone is interested in his task—and all work is done collectively to achieve the ultimate project objectives in a fast changing project environment. Coordination in such a case is not required. However, such an ideal environment is rarely met in construction projects. Coordination is essential both within and among the various departments to fill up the voids created by changing the situation in systems, procedures and policies.

The planning chief can play an important role in smoothening up the project coordination function by performing the following tasks:

- Communicating promptly the monitored information to all concerned for taking corrective measures to prevent adverse situations;
- Creating a climate of cooperation by avoiding interdepartmental conflicts and resolving all issues affecting the progress of work;
- Providing a proper flow and record of the monitored information through monthly information reports, minutes of meetings, project bulletins and liaison letters; and
- Pursuing all the planning and monitoring issues raised by the departments to their logical completion.

Professional role.   The effective implementation and smooth functioning of the planning system primarily depends upon the professional competency of the planning chief. He should be able to plan the project, organise the control system, employ monitoring tools and techniques, design the codification system, develop the management information system, and create a conflict-free and harmonious working environment. All this requires a high degree of professional skills; some of these are acquired while others come with experience.

To make the planning system effective, the professional qualifications of the planning chief should be at least a degree in engineering, a post-graduation in construction management or business ad-

ministration (MBA) with skills in use of project management software, and adequate construction experience in various fields including: site-work, estimating and costing and planning. He should have worked as the planner on a major project. Additionally, a chief planner should have an analytical mind, a creative approach, highly developed conceptual skills, a past record of team-working, devotion to duty and a strong sense of purpose.

Roles when 'planning starts' and when 'specialised planning function ceases.' In the initial stages of preparation of a project plan, the chief planner needs to win over the confidence of the project team as well as the persons holding vital connected work documents like feasibility studies, and quantity and cost estimates. No plan can be prepared without studying these documents. For various reasons, the persons holding these may hesitate to part with them. While some may fear a criticism of their work, others may consider planning a fault-finding exercise.

The plan-do-monitor-replan continues during the construction phase of the project till a saturation point is reached, when specialised planning is no longer needed. If the project implementation is based on a sound plan and the planning system functions effectively, this planning saturation stage arrives when the major portion of the project work (say 60%–70%) has been executed. By then, all the members of the project team would have become familiar with the plan for execution of the balance works and generally, the project plan does not need further re-planning. It is ironical that at the saturation stage, which marks the effectiveness of the planning system, the need for specialised planning and monitoring ceases and the planning team becomes almost redundant. Unless needed elsewhere, some short-sighted management team may attempt to ease out the planning staff to save overhead costs.

No two projects are alike. Each new project enhances the planning skills of the planners. In every project, the planners have to conceptualise the development of the project right from the scratch to near completion. They have to plan and monitor against inevitable and unforeseen situations, and go through numerous stresses and strains of the projects' activities. They have to compile the planning data from their experience. It is not easy to find planners who are experienced in the development of project time, resource and cost plans, and can also design and implement the project control system. It is thus advisable to well utilise their services, within the project or elsewhere, rather than easing them out halfway through the project.

2.5.2 Functions

The primary role of the project planning cell is to assist the project manager and the management team in planning, coordinating and controlling the project, so as to achieve defined time goals with minimum costs. Within the framework of this role, the planning cell plans the project and provides planning information continuously to the management team on the planned targets, actual performance and the likely trends along with the remedial measures.

The functions to be performed by the project planning cell and its composition vary with the size and complexity of the project. For example, a large-size building construction project may have a planning cell consisting of: a planning manager, a civil engineer, an electrical or mechanical engi-

neer, a systems engineer and a draftsman. On the other hand, in a similar small-size project, all the functions may be entrusted to one planning engineer only. Further planning, estimation and cost accounting functions can be best performed if they are placed under one head and the participants work as a team, sharing data and evaluating information.

Generally, the chief planner performs the following functions:

- Formulating the planning and control policies and the data processing system;
- Making the project time, resources and cost baseline plans, and replanning when necessary;
- Formulating the work organisation plan;
- Establishing the planning and performance measuring standards;
- Mobilising and allocating resources for various construction sites;
- Collecting and collating site data about the activities in progress; employment of manpower, equipment and materials, etc. and also evaluating the resource productivity;
- Monitoring the progress of specified performance objectives;
- Tracking variances of labor output and machinery utilisation of productivity standards and providing feedback-based productivity information to the site executives;
- Updating resource productivity norms, and planning the data and unit rates of work;
- Maintaining the technical records, publications and the project library;
- Participating in technical meetings and preparing their minutes;
- Coordinating all technical activities;
- Rendering assistance to the site executives on construction planning, formulating monthly targets and managing the project information system including submission of reports at pre-determined frequency to all concerned; and
- Setting up a project control room displaying vital up-to-date information.

The aforementioned list is only indicative and not exhaustive. It may be noted that the pre-requisites for effective functioning of the planning personnel include: the management-backed drive for making site executive plan-conscious, the involvement of project engineers in planning and controlling activities, the existence of a well-coordinated and harmonious environment and, on top of all this, the role played by the project planning chief.

APPENDIX B

Project Success Strategy Development

❑ B.1 INTRODUCTION AND SCOPE

A construction project is a temporary endeavour that is undertaken to create a unique facility in conformity with needs of corporate/sponsor. The urgency and integration of the complex process-es, for managing the project scope, time, resources, costs, and quality is subject to unpredictable changes in internal and external environments. Some projects succeed in achieving their specified objectives and other fail. The factors resulting in the success (or failure) of a project have been stud-ied by many project management practitioners and academicians. The basic questions that arise are:

- What are the criteria for project success and how to measure these?
- What are project success key factors?
- How to develop strategy for project success?
- Significance of key performance indicators in success strategy implemetation.

The above aspects are covered briefly in subsequent paragraphs.

❑ B.2 CRITERIA FOR PROJECT SUCCESS AND HOW TO MEASURE THESE?

In simple words, the success of a project means the successful achievement of project objectives, stipulated in terms of 'timely completion , within budgeted cost, specified quality specifications' and meeting assured facility functionality requirements. Generally, it can be said that a project is completed successfully, if it meets the following completion criteria:

- The project achieved its specified functional objectives and its purpose with required quality;
- Its completion is within the pre-stated allocated time period, budgeted cost, specification level, and functional purpose;
- It is accepted by the owner, promoter, and user;
- Corporate and project management can use the clients' name as a reference;
- It conforms to the given scope of work with minimum or mutually agreed upon scope changes;
- Its completion satisfies the project team and the people; and
- There are minimal disputes and conflicts among the stakeholders.

This traditional criteria, which stood grounded in the past, cannot be considered adequate for the success or failure of modern projects, as it raises many questions, such as how to measure success from angles of various stakeholders/participants. These stakeholders include sponsor, project management, corporate, contractor, vendors, and the user. They view success from different angles leading to different criteria for success:

1. **Sponsor success.** His success criteria is to see that the project is completed as per specified objectives in order to get the value for money? It implies that the project is functional for the purpose for which it was conceived. It should not be the case like 'the surgical operation was successful but the patient died'.
2. **Project Management Success.** It is measured to determine, as to how far the employed resources have been utilized productively for producing the planned outputs and achieve objectives.
3. **Corporate success.** The corporation will be satisfied with the successful outcome, if it promotes growth and reputation.
4. **Contractor's and vendor's success.** Their satisfaction depends upon the targeted profitability.
5. **Users' success.** They will be satisfied if the functionality of the facility created meets their expectations.

❑ B.3   PROJECT SUCCESS KEY FACTORS

The key success factors in a modern project are subject to internal and external forces, as depicted in **Figure B.1**.

There are numerous research findings and opinions of the experts on key factors of the project success. To quote an example from the study of the key factors influencing to the project success, Emanuel Camilleri (2011) summarized his findings. It is based on the documented 252 opinions of the experts. The top 6 key success factors, in the order of importance are outlined below:

- Effective implementation of Project Planning and Control System;
- Strategic Fitness with project objectives and the stakeholders commitment for achievement;
- Matured Project Scope with minimum changes;
- Smooth information Communication at appropriate channels;
- Effective Management and Leadership; and
- Management of Project Risk.

Dr. Kumar Neeraj Jha (2011) studied in detail, the various attributes for the project success. Out of these, he highlighted the following critical success factors:

- Positive attitude of PM and project participants;
- Effective monitoring and feedback by the project team members;
- Selection of PM with proven track record at an early stage by top management;

Figure B.1

Construction Project Management Key Success Factor Model
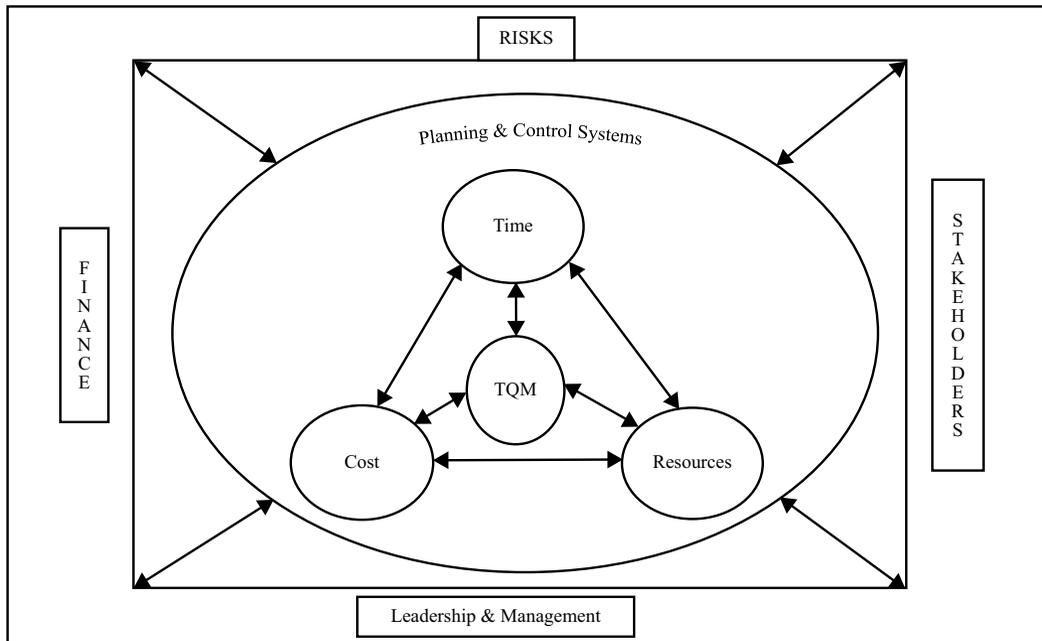
- Coordinating ability and rapport of PM with the team members and the sub-contractors;
- Project Managers technical capabilities; and
- Leadership quality of PM.

It can be broadly inferred that implementation of an effective planning and control system is the most important key factor that influence the success of a project.

Guidelines for Project Planning and Control System Effectiveness.   The guidelines for the success of the planning and control system are tabulated below:

- Minimize start up problem;
- Plan the time schedule in the initial stages of the project and revise the schedule when the contract is finalized;
- Forecast important events and risky situations;
- Estimate costs and value of work, package-wise;
- Forecast cash flow and ensure adequate funding till completion;
- Assign KPI and responsibilities;
- Administer contract fairly to avoid disputes and litigation;
- Ensure timely availability of right quality of resources at the right place;

- Focus on logistic requirements particularly the acquisition of materials;
- Continue "What if?" approach;
- Know and respond to the real status of the project;
- Regularly monitor progress and take remedial action in case of deviation from the planned path;
- Implement resource control mechanisms;
- Conduct third party regular reviews by internal and external parties; and
- Establish and control contractor's performance.

❑ B.4 PROJECT SUCCESS STRATEGY

Construction projects are prone to risks, which in turn results in changes from the project planned path for accomplishing the objectives. For successful completion of project, it is necessary to formulate and implement strategy based on how to manage the key success factors. The guidelines for managing the success factors are as follows:

1. Establish a well designed project planning and control system for managing work scope changes, product quality specifications, timely milestone completion, productive resource utilization, working within budgeted cost, and changing risky environments.
2. Set up the project organization for managing the integrated planning, and control system.
3. Ensure Expect sponsors' and contractor's support for timely finance provisioning as per prior agreement and have minimum scope changes.
4. Create goal-oriented motivated project environment through effective leadership and ethical behavior at all levels.
5. Monitor the Success Strategy regularly and apply corrective measures, as and when necessary.
6. Seek commitment of stakeholders to meet their obligations and to abide by project success criteria using long term and short term Key Performance Indicators as explained in the next paragraph.

Note. The goal-oriented regularly-monitored project plan in controlled project environment with effective leadership at all levels, makes all the difference in achieving project objectives

❑ B.5 SIGNIFICANCE OF KEY PERFORMANCE INDICATORS (KPI) IN PROJECT SUCCESS STRATEGY IMPLEMENTATION

What are Key Performance Indicators (KPI).   Key Performance Indicators (KPIs) refer to the set of quantifiable progress targets assigned to key personnel and to measure their performance at the predefined times. In simple words, monitored KPI evaluate the key person performance and how well the project is moving towards meeting strategic goals.

How Key Performance Indicators (KPI) are defined.   After the project organization has analyzed its project mission, identified all its stakeholders, defined its goals, and developed its project management strategy to achieve these goals. It needs a yardstick to measure progress toward those strategic goals. Key Performance Indicators (KPI) are the tools that are employed to review the project as well the stakeholders performance status. An effective KPI define the following:

Objective with Commitment   Specific goals and responsibility for their achievement. It needs commitments of each stakeholder, project team member, and even supervisors to achieve the goals. Preferably KPI should be agreed/proposed by the concerned manager/individual before they are approved by the top management.

Quantifiable Performance   KPI's assigned goals must be quantifiable and measurable. Generally the KPI should be about 5 to 10 specific points for each concerned manager/ individual.

Practical Actionable Approach   KPI can be put into practice to effect desired change within the present company processes and objectives. Fulfillment of KPI must not be linked to the factors beyond the control of the company.

KPI Monitoring   It helps to determine KPI status. KPI must have a specific time-frame action plan divided into key check points.

Illustration: Some KPI for the first six months of a New Project.   Few KPI's identified from the project management baseline plan and assigned personally to the stakeholders, managers, and supervisors, and which become their commitment for the first six months, are listed below:

- Milestones achieved vs. planned;
- Number of interdependencies project tasks delayed
- Backlog of completion of Project Scheduled Tasks more than one week;
- Schedule Performance Index (SPI) Variation;
- Ratio of Total Direct Workers Costs vs. Total Manpower Costs;
- Budgeted Cost of Work Scheduled (BCWS) overrun/underrun Status;
- Material delivery deadlines met and delayed;
- Deviation from the planned budget;
- The Milestones deviation from the planned time schedule in calendar dates; and
- Earned value vs planned value extent and time deviations.

KPIs can be assigned using Responsibility Assignment Matrix (RAM), which is described in Section 2.4.7 **Chapter 2**. During project implementation, the plan-do-monitor-communicate-replan (when necessary), is a continuous process. In this context, the strategy for project success and KPI should be reviewed regularly and corrective measures should be applied, as necessary.

Defining Project Activities

An activity can be defined as an identifiable, quantifiable, measurable, costable, assignable, and controllable lowest level, element of work, which must be performed during the course of a project for achieving the project mission.

The activity definition processes, the tools employed and the outcome of each process are tabulated below:

Activity Definition Processes	Processing Tools & Techniques	Outcome
Identifying Project Activities	Project WB Structure Functions WB Matrix Repetitive WB Matrix WBS Templates	• WBS • Activity List
Estimating Activity Duration and Activity Resources	One-time Estimation Method Three-times PERT Estimation Method Non-linear Distribution Method Resources Planning Data	Activity Duration
Defining Activity Database	Duration Supporting Resources Activity Cost Estimation Activity Earned Value Estimation	Activity Database

Project Work Breakdown Structure (WBS) is the basic tool that is used to identify activities. WBS methodology facilitates the splitting of the work scope of project into hierarchy of breakdown levels of sub-projects (end products or deliverables), tasks, work packages, and activities.

Activity time duration estimate is at the core of all project time management processes. Activities require resources for their timely completion. In construction projects, the time duration is generally related to the quantum of resources employed. Information about physical resources such as men, materials, and machinery, which are needed for the execution of each activity, enables forecasting of the physical resources and planning of production costs and the cash flow. The estimation of physical resources is covered in **Chapters 7–9**.

An activity is defined in terms of its core database. In construction, activity core database includes work quantity, execution time (duration), resources requirement, production cost and earned (budgeted) value that is associated with the accomplishment of the activity. Some of the data is determined during the activity duration estimation process; while remaining data is derived during the project time-scheduling, resources planning, and cost budgeting processes. This database is vital for planning and monitoring of the project work, especially with commonly used project management software.

The inputs to the activity definition process are the site data and available project documents. These documents may include, project charter, WBS, technical and commercial studies, investigations, designs and drawings, estimate of quantities (BOQ), construction method statements, contract documents, and the project planning data. These should be studied prior to commencement of Project Activities Identification processes.

This chapter is divided into the following sections:

1. Project Work Breakdown Levels Development Methodology
2. Project Activities Identification Methods
3. Activity Duration Estimation
4. Activity Costs and BOQ Work-Item Relationship in Contracted Projects
5. Activity Database

Project Work Breakdown Structure is the basic tool that is used for managing project. It is at the core of activity identification, cost planning, organisation design, risk identification, data organisation, and many other processes. **Appendix C** at the end of this chapter is devoted to project Work Breakdown Structure applications in project management.

❑ 3.1 PROJECT WORK BREAKDOWN LEVELS DEVELOPMENT METHODOLOGY

3.1.1 Project Work Breakdown Levels Defined

The work scope of a project can be broken down into manageable parts that can be arranged in a hierarchical order into levels of sub-projects, tasks, work packages, and activities. Each descending level signifies an increasingly detailed description of the elements in the preceding project level. An activity is the lowest level element of work, which is usually a part of the work package.

Work Breakdown Structure (WBS), as already defined in **Chapter 2**, is a "deliverable- focused hierarchical grouping of project elements that organises and defines the total work scope of project." Deliverables on the other hand are defined as tangible and measurable parts of the project. This definition is elaborated in **Appendix C**.

Some academician and practitioners restrict the work breakdown process into deliverables or task levels while, others select work packages or activities levels. At work package level time and cost can be worked out accurately in deails and as such this level is generally used for controlling cost and time. But for activity identification and time progress monitoring, breakdown to activity level is a must .

Work Breakdown Structure of Construction Projects, as considered in this chapter, is a visual representation of the construction works split down to sub-projects (deliverable end products), tasks, work packages, and activity levels. The Work Breakdown Structure of a construction project down to, at the activity level is commonly called as Project Work Breakdown Structure (PWBS) or just WBS. The WBS levels can be defined and classified as shown in **Table 3.1**.

Table 3.1

Definition and Classification of Project Work Breakdown Levels

Level	Description	Main Criteria
1	Sub-project level	An independent, deliverable end product requiring processing of multitasks having large volume of work.
2	Task level	An identifiable and deliverable major work containing one or more work packages.
3	Work-package level	A sizeable, identifiable, measure, cost-able and controllable work item/package of activities.
4	Activity level	Identifiable lower-level job, operation, or process, which consumes time and possibly resources.
5	Operations level	A lowest level day-to-day operation, or process, which is part of an activity.

Note: Project title can be defined as level 0.

Following indirect and non-deliverable items of work are generally not included in the WBS:

- Activities that do not directly contribute to end products or deliverables such as functional responsibility, pre-contract development activities, resources procurement, and financing of the project.
- Activities relating to testing, reworking, handing over, demobilisation, and the project close-up.

3.1.2   Project Work Breakdown Salient Features

Each level has certain features associated with it: these are listed in **Table 3.2**. However, it may be noted that level categorisation is a broad concept and at times their overlapping or further detailing may become unavoidable.

3.1.3   Illustrations: Project Breakdown Levels of 2000 Housing Project

Development of WBS from top-down levels is illustrated with examples from 2000 Housing Units Project. The project work include: construction of residential apartments, educational buildings, public buildings, a civic centre, connected external utility services, and landscaping. The residential accommodation superstructure was of precast concrete construction. The 2000 apartments were

Table 3.2

Project Work Breakdown Levels of a Medium-Size Project: Salient Features

S. No.	Features	Sub-project	Task	Work Package	Activity
1.	Level designation	Level 1	Level 2	Level 3	Level 4
2.	Work interdependency with other jobs	Independent; can proceed without interference	Generally independent	Mostly interdependent	Interdependent
3.	Type of Project Plan where used	Corporate Strategic Plan	Project Conceptual Plan	Project Preliminary Plan	Project Master Plan
4.	Nature of Time schedule	Summary schedule	Summary schedule	Preliminary schedule	Master schedule
5.	Duration unit	Months	Months/Weeks	Weeks/Days	Working Days
6.	Organisational responsibility	Project Manager	Project Team	Work Centres In-charge	Work Supervisor

Note 1: Work breakdown levels are not related to cost, but as a rough guideline each work package cost can be sizeable (say vary between 0.05%–5% of the cost of the project) and preferably time duration of an activity should not exceed 25 working days.

Note 2: In a large size construction project, each of the sub-projects can be treated as a project, thus creating a multi-project environment.

grouped into residential buildings consisting of 334 near identical modules, where each module comprises of six flats. The precast production and erection was geared to achieve a peak of five flats superstructure equivalent to per working day. The total value of contract work was approximately US $150 million and the project should be completed in 36 months, as per the contract. This project scope of work is listed in **Table 3.3**. Work breakdowns of the 2000 Housing Units Project are sketched in **Exhibits 3.1** through **3.3**. These are explained in subsequent paragraphs: **Table 3.3**.

Sub-projects level. Sub-projects are derived by dividing the scope of project work into independent large-volume mini projects or deliverables, which could be progressed in a systematic manner, without interference from another group of work. In a major project, each of these sub-projects can be headed by a senior construction manager. For instance, in the 2000 Housing Units Project, each type of residential, educational and public building and external utility services can be designated as a sub-project (see **Exhibit 3.1**).

Tasks level. The project or sub-project work can be split up into various tasks. A task refers to an identifiable and deliverable major work. It is an entity in itself that can be performed without much interference from other tasks.

In the 2000 Housing Units Project, the construction work in each residential building, are grouped under three main tasks, i.e. foundation, superstructure, and finishes (see **Exhibit 3.2**). Execution of

Table 3.3

2000 Housing Units Project Scope of Work

1.	**Residential buildings (334 modules) with specified External utilities**	
	- 3 Bedroom flats	1400
	- 2 Bedroom flats	600
	Total built up area	267,333 m²
2.	**Educational buildings**	
	- Nursery	2
	- Kindergarten	4
	- Primary school	5
	- High school	4
	Total built up area	32,804 m²
3.	**Public buildings**	11,600 m²
4.	**External utilities Services**	
	Filtered water supply/piping (32 km):	32 km
	Unfiltered water supply/piping (36 km):	36 km
	Sewage disposal/piping (21 km)	21 km
	Storm water drainage/piping (12 km)	12 km
	Pipe gas supply/piping (27 km):	27 km
	Electric power supply and : distribution network/ cabling (111 km)	111 km
	Telephones/cabling (53 km)	53 km
	Substations and pump houses (3000 sq.m)	3000 m²
5.	**Roads, footpaths, pathways, sports facilities, gardens and landscaping**	210,000 m²

each of these residential building tasks was entrusted to a task responsibility centre, headed by a manager or a senior engineer.

The task level can be used in developing project plans, the design-preparation plan and the contract tendering plan. A task is generally supported by its design package. Each task is assigned time and cost objectives, along with planned resources for accomplishing the task objectives. Task level is generally used in the project-summary plan and the design-preparation plan.

Work package level. A project task can be further subdivided into one or more work packages. *Each work package contains activities, which are identifiable, sizeable, measurable, cost-able, assignable and controllable packages of activities/works*. A work package, generally, consists of more than one activity. In the case of a multi-activity work package, each activity has its own unit of measure which, in some cases, is related to the bill of quantities. It is mandatory requirement that a work package should be expressible in one measure unit, such as length, area, or volume, for the

Exhibit 3.1

2000 Housing Units Project Sub-project and Task Level Work Breakdown

```
                        ┌──────────────┐
                        │   HOUSING    │
                        │   PROJECT    │
                        └──────────────┘
```

HOUSING PROJECT

- Residential buildings
- Educational buildings
- Public buildings
- External Services

Sub-project level

- 334 nos. modules
- High school 4 nos.
- Primary school 6 nos.
- K.G. 4 nos.
- Nursery 2 nos.

Task level

- Res. Bldg Foundation
- Res. bldg. Super-structure
- Res. bldg. Finishes

- Filtered water supply system
- Sewerage system
- Road/pavements etc.
- Service buildings

- Unfiltered water supply system
- Electrical system
- Gas supply system

- Police station
- Party Office
- Social centre
- Sub-shopping
- Hammam
- Mosque

- Health centre
- Youth centre
- Shopping complex
- Post office
- Swimming pool
- Air raid shelter

Exhibit 3.2

2000 Housing Units Project: Construction of Residential Building: Tasks and Work Package Levels Structure
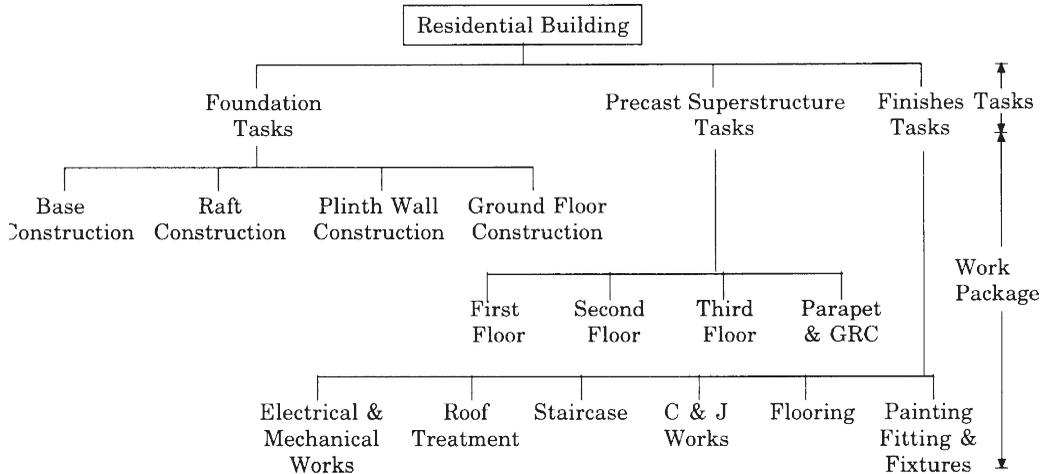
purpose of measuring performance. In case, if it is not possible to define its unit of measure, then its work content should be further divided into more than one package. But there is a wide gap in size and other characteristics that defines a work package, as it has no single solution. However, the following guidelines should be considered while defining a work package.

- Identify the physical accomplishment of a work item;
- Avoid overlapping from the preceding and succeeding work packages;
- Reduce the parallel activities;
- Minimise the sequential inter-dependent activities;
- Defines the time and cost estimates;
- Assign work-incharge to supervise the entire work package;
- Eliminate time-breaks, if they occur in the execution of sequential activities;
- Identify the type of resource needed for execution;
- Separate the quality acceptance criteria; and
- Reasonable size so that it can be assigned to a suitable work-incharge. As a rough guide, the package size can be kept within 0.05%–5% of the cost of the project.

If some of the work packages that are under consideration do not fulfill above criteria, then it should be further decomposed into more than one work package, if necessary.

In the 2000 Housing Units Project, foundation work of a residential building was broken down into four work packages; base, raft, plinth wall, and ground floor slab. **Exhibit 3.2** shows the tasks and the work packages for the construction of a residential building of the Housing Units Project.

Activity Level.   A work package can further be broken down into various activities. An activity consumes time and resources. Each activity is identifiable, sizeable, measurable, cost-able, assignable and controllable.

- **Identifiable**: Work element in which work can be executed with the least interference from the preceding and succeeding work packages. In general, each activity must be identifiable and quantifiable interdependent activities, which consume time and resources.
- **Sizeable**: An activity that consumes time, resources, and is of reasonable size. The smaller the size of the activity, the lesser is the margin of error in estimating the time and cost. The estimated errors, whether positive or negative, usually reduce the margin of errors when considered collectively in a work package. However, there is a size limit, as small size can also unnecessarily increase the number of activities, whereas, on the other hand large size can make monitoring difficult.
- **Measurable**: A work package, generally, consists of more than one activity. In case of a multi-activity work package, each activity has its own unit of measure, which, in some cases, is related to the bill of quantities. It is desirable that an activity should be expressible in one unit of measure, such as length, area or volume, so that its performance can be easily measured. In case, it is not possible to define it into a single unit of measure, then it should be further divided into more than one activity, each enabling performance measurement. .
- **Cost-able**: Each activity consumes resources. Its direct cost can be defined as the sum of the direct costs of the works that are constituted in the activity. The cost of executing a work package, while working efficiently under normal conditions is termed as the standard work package cost. Moreover, it forms the building block for planning, budgeting, and controlling project costs.
- **Assignable**: Organisationally, a project is divided into a number of construction responsibility centres or cost centres. Each of these centres is allocated resources and assigned targets that are been expressed in terms of work packages. Each work package is further divided into activities. Each of these work centres consists of one or more work packages. Each work centre is assigned targets that needs to be achieved and is allocated resources to accomplish the targets. The activity is at the lowest level, which can be assigned to a single person.
- **Controllable**: T he project performance can be best measured in quantities and compatible activities. The smaller the size of an activity; the greater is the precision in measurement and controlling of performance.

In the 2000 Housing Units Project, foundation construction task of a residential building can be broken down into 27 activities (see **Exhibit 3.3**).

Operations Level.   An activity comprises of one or more operations. Each operation includes, a part of the work content of the activity. It generally has a particular type or a fixed group of resources associated with it. It is performed during the scheduled time duration of the activity. Some operations may start with the commencement of the activity, while others may take place during its time duration. In some situations, performance periods of operations may overlap. In the 2000

Exhibit 3.3

2000 Housing Units Project Residential Building
Work Packages and Activity Level Work Breakdown Structure
Construction of Foundation Residential Building

Foundation Tasks

Base Construction Work Package   Raft Construction Work Package   Plinth Wall Construction Work Package   G. Floor Construction Work Package   — Work Package

Layout   Shuttering   Reinforcement   Concreting   Curing

Earthwork   Base Preparation   Blinding   Bitumen Coating Raft-sides   Concreting   — Activity

Shuttering

Layout   Erection

Placing   Deshuttering   Curring

Layout   Excavation   Levelling | Shuttering   Concreting

Anti-Termite Treatment   Polythene Sheeting   Preliminary Works   Shuttering   Mesh Fixing   Concreting   Curing

Bitumen Coating Plinth Wall   Back Filling   Plinth Filling   Anti-termite Treatment   Polythene Sheeting

Activity Breakdown into Operations
Operation 1
Operation 2
Operation 3
Operation 4

Housing Units Project, operations involved in activity 'concreting raft' of foundation work include:

- Cleaning and preparing inner side of the raft for concreting;
- Pumping concrete;
- Spreading and vibrating concrete; and
- Finishing of top concrete surface.

Operations are not considered during the network modeling and analysis stage, except that the sum of the costs of operations equals the activity cost. They form the basis for allocation and scheduling of resources of each activity.

3.1.4   Significance of Work Breakdown Levels

The construction projects are best, organised by tasks, controlled by the work packages, and pro-grammed for day work, by using planned operational level that are monitored by the activities.

In a project master plan, each work package is assigned with its performance objectives. These are generally stated in terms of its completion period, standard cost, resource-productivity stan-dards, and the earned value or the standard sale price. The measure of performance thus, gets closely linked with the execution of its work packages.

Work packages form a common base for linking the key functions in management of a proj-ect. This leads to the simple-management theory of managing, designing, estimating, planning, organising, directing, communicating, and controlling by work packages. A project planner uses activity, as the common database for planning a project. The activity duration forms the basis for time planning and scheduling of project work. Detailed information about resources, such as men, materials, and machinery that are needed for execution of each activity, enables the preparation of resource forecasts. The activity contract-value (sale price) is used to determine the income and cash-flow forecasts. The activity base is vital for monitoring the progress of the project work. In the 2000 Housing Units Project foundation construction task can be broken down into 27 activities (see **Exhibit 3.3**).

❑ 3.2   PROJECT ACTIVITIES IDENTIFICATION METHODS

3.2.1   Activities Identification Approach

The base for the identification of activities in a project is WBS, but the structure format and meth-odology depends upon the nature of the project and its purpose. In general, these approaches can be categorised as follows:

Nature of Project	WBS Patterns	Exhibit References
Simple Projects: Pumping Station Construction	Tree-structure and Numbered levels	Exhibit 3.4
Complex Projects: 2000 Housing Units Project	Tree-structure	Exhibits 3.1–3.3
Simple Repetitive Projects: Factory Project	Task Matrix	Exhibit 3.5
Complex Repetitive Projects: Educa-tion Building Complex	Combination of Tree-structure and Task Matrix	Exhibits 3.6–3.7
Complex Programme New Canton-ment Construction	Tree-structure	Exhibits 3.8–3.10

3.2.2 WBS Development of Simple Project: Illustrated by Pumping Station Sub-Project

In a project, the construction of a pump house of size 40000 mm length × 8840 mm breadth was tendered as one contract (**Figure 3.1**). The scope of work included the construction of the pumping station building, the procurement, installation of six pumps and one gantry crane, the provision of connected internal services and, the commissioning of the pump house.

The work-breakdown of the pumping station contracted work can be developed by splitting the work into divisions or levels till the desired activity level for planning and controlling the progress of the work is achieved. The Work Breakdown Structure that lists the involved activities is drawn in **Exhibit 3.4**. It is developed using the following procedure:

a *First division*: Showing tasks. The works in the pumping station sub-project can broadly be divided into two task groups-Building Construction tasks and Electrical & Mechanical Tasks.
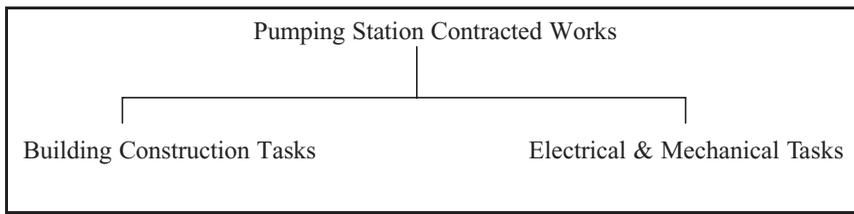
b *Second division*: Depicting work packages. Each of the task group derived in the first division can further be subdivided into work packages as follows:
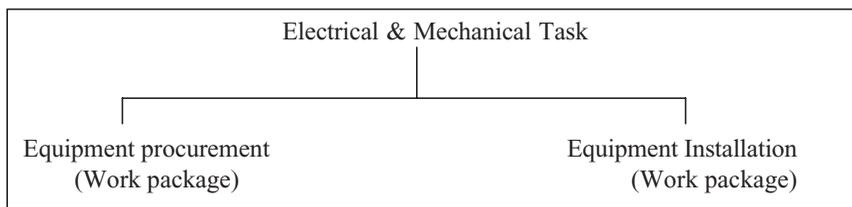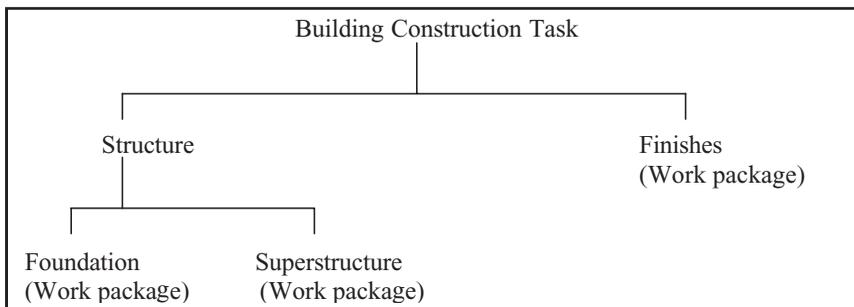
c *Third division*: Representing activities. Each of the work packages can further be split into activities. For instance, activities constituting the work package structure consist of Excavation,

Figure 3.1

Pumping Station Project

Line Plan

Elevation

Section AA′

Isometric View
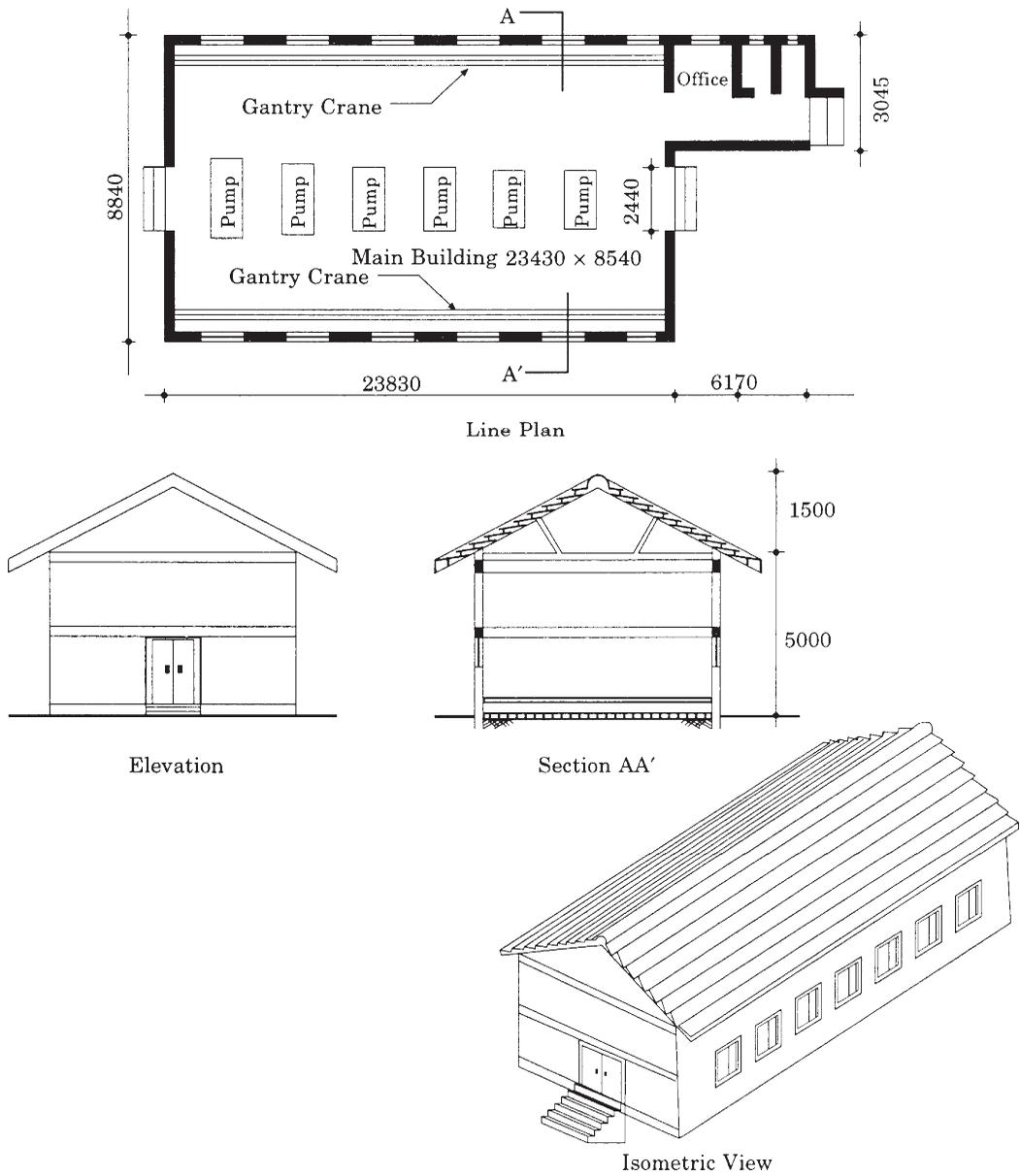
Foundation, Walls and Roofing. Similarly, the activities of the other work packages can also be derived. The activities for the pumping station sub-project are structured in a hierarchy tree format in **Exhibit 3.4**.

Exhibit 3.4

Pumping Station Project

Pumping Station Project

Work-breakdown Structure

Pump House Building — E/M Works

Foundation — Superstructure — Flooring and Finishes — Internal Services

Excavation — Foundation Wall

Wall Above Ground — Roofing

Upto Sill — Upto Lintel — Upto Tie-band — Tie-band — Gable End

Fabrication & erection of trusses — Sheeting

Flooring — Internal Plaster — External Plaster — Painting & Finishes — Site Clearance

Electrification — Water Supply & Sanitary Fittings

Procurement of Equipment & Machinery — Installation & Commissioning

Gentry Crane — Pumping Sets & Accessories — Pipes and Accessories

Gantry Erection — Pumping Sets

Foundation — Installation — Pipe Work — Commissioning & Testing

This structure can also be depicted in a standard levels-labeled table as follows:

WORK BREAKDOWN STRUCTURE OF PUMPING STATION SUB-PROJECT

1.   **Pumping Station Project**

  1.1   **Pump House Building**

    1.1.1   **Foundation**
- 1.1.1.1   Excavation
- 1.1.1.2   Foundation

    1.1.2   **Superstructure**
- 1.1.2.1   Wall Above Ground Level
- 1.1.2.2   Roofing

    1.1.3   **Finishes and Essential Services**
- 1.1.3.1   Internal plaster
- 1.1.3.2   Laying Floor
- 1.1.3.3   External plaster
- 1.1.3.4   Painting and finishes
- 1.1.3.5   Site Clearance

    1.1.4   **Internal Services**
- 1.1.4.1   Electrification
- 1.1.4.2   Plumbing and sanitary fitting

  1.2   **Electrical and Mechanical Works**

    1.2.1   **Procurement of Equipment**
- 1.2.1.1   Procurement of crane gantry
- 1.2.1.2   Procurement of pumping sets
- 1.2.1.3   Procurement of suction/delivery pipes

    1.2.2   **Installation and Commissioning of Pumping Sets**
- 1.2.2.1   Erection of gantry
- 1.2.2.2   Pumping sets
  - 1.2.2.2.1   Foundation of pumps
  - 1.2.2.2.2   Installation of pumping set
  - 1.2.2.2.3   Fixing of suction and delivery pipes
  - 1.2.2.2.4   Commissioning of pumping sets

The breaking down of the project work into large detailed components (like minor operations or processes) should be the avoided to make a WBS, a manageable tool.

3.2.3 Simple Repetitive Project: Illustration

This technique is generally used for determining functional activities at the feasibility stage or in the turn-key projects. In this, the tasks or work packages included in a project are listed vertically, while the various functions or connected aspects are listed horizontally, in a hierarchy. The interconnection between the tasks and the functions, where applicable, represents the activities.

Factory construction project.   Consider the case of a medium size factory, which was assigned top priority for construction. Since the project was to be completed with foreign collaboration, it was decided to drastically cut down the usual departmental procedures in order to speed it up.

The project consisted of the construction of factory buildings, office and living accommodation, temporary accommodation for construction staff, and essential services. The sitting board took a month to finalise the layout and other connected preliminaries. The go-ahead signal for the survey of land and project preliminaries was accorded immediately on the finalisation of location studies. The final approval for the project was expected to take another month. All work related with the procurement, installation, and commissioning of the factory equipment was to be undertaken by the foreign consultant.

The project was planned for completion in two phases, which were:

- Phase I: To commission the factory within 18 months after the project go-ahead signal is issued. This phase also include essential office and living accommodation.
- Phase II: To complete the remaining accommodation within six months after the completion of phase I.

In order to plan and monitor the execution of the project, a project planning cell was established, where planning chief was made a member of the project construction team.

The task matrix prepared by the planning chief to derive activities for developing the project preliminary plan is given in **Exhibit 3.5**.

3.2.4 Complex Repetitive Work Breakdown Matrix: School Construction Sub-project of 2000 Housing Units Project

In projects involving repetitive or similar activities, the Work Breakdown Structure method can be used to identify activities in one building/facility/sector, while the matrix method can assist in determining activities in other similar areas.

Consider the construction of schools in the 2000 Housing Units Project. The project includes two nursery, four kindergarten, five primary, and four high schools. These schools had similar construction but are varied in size. The Work Breakdown Structure of the primary school, reflecting work packages and the connected activities is shown in **Exhibit 3.6**.

Primary School work packages and activities are as follows:

Primary School Work Package and activities		
S. No.	Work Packages	Connected Activities
1.	Footing Wings-I and II	Excavation and footing, stub column and plinth beam and ground floor slab.
2.	Superstructure Wings-I and II	Wing I Ground floor column, first floor beam and slab and roof structure. Wing II First floor structure.
3.	Structure of gymnasium	Foundation, portals and slab.
4.	Building Frame	Block work, concealed pipes or conduits, internal plaster, AC ducting and piping, roof treatment, wiring and external plaster.
5.	Finishes	Tiling, preliminary paint, equipment installation, carpentry, joinery and metal work, fitting and fixtures, final paint and balance completion.

The activities of the primary school can be listed in the main column of the Task Matrix, as shown in **Exhibit 3.7**. The other school activities, being similar to that of the primary school, can be easily

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Exhibit 3.5

Planning of a Factory Project during Feasibility Stage Task Matrix

Task Code	Task Description	Activities with Durations in Months			
		Accomplish-ing	Designing	Con tracting	Execution
A	Preliminaries	1	–	–	–
B	Project Sanction	1	–	–	–
C	Land Procurement and Survey	2	–	–	–
D	Factory Building	–	1	2	12
E	Office and Living Accommodation Phase-I	–	1	2	9
F	Office and Living Accommodation Phase-II	–	1	2	6
G	Temporary Storage Accommodation	–	–	1	3
H	Installation of Tube-wells	–	–	–	2
I	External Water Supply and Sanitation Phases I and II	–	1	2	3
J	External Electrification	–	1	2	3
K	Air Conditioning Factory and Office Building	–	1	2	2
L	Furniture for Phases I and II	–	1	1	4

identified and tabulated in the matrix. In particular, the duration of the activities can be incorporated as shown in the **Exhibit 3.7**.

3.2.5   Complex Programme WBS: New Cantonment Projects

Background.   This case history illustrate the application of the Work Breakdown Structure technique in developing the tasks involved for planning a military cantonment construction project. This case can be used as a guide for developing programme for new township and housing complexes. The team assigned for preparation of the project plan studied the information (then available) from the following sources:

- The sitting board report;
- The layout plan;

Exhibit 3.6

Primary School Construction

Work-breakdown Structure

Footing Wings I & II Work Package | Superstructure Wings I & II Work Package | Gymnasium Structure Work Package | Building Frame Work Package | Finishes Work Package

Excavation & Footing | Stub Columns & Plinth Beam | Ground Floor

Foundation | Portals | Slab

Superstructure Wing I | Superstructure Wing II

First Floor Structure

Ground Floor Columns | First Floor Beam & Slab | Roof Structure

Blockwork & Conduits | Pipes Plaster | Internal & Piping | Ducting Treatment | Roof & Wiring | Screed Plaster | External

Tiling | Preliminary Paint | Equipment Installation | Carpentary & Joinary | Fitting & Fixtures | Final Paint | Final Completion

- The project administrative approval;
- The existing outline of ten-year plan for the construction of the project;
- The progress reports of the works under execution; and
- The policy letters covering the brief history of the project, the scope of the work and the limitations or constraints imposed by the higher management from time to time.

Further details for making the time plan were obtained by discussing the relevant aspects with the heads of sections and applying the famous questions—Who? What? Where? When? Why? How?—as and when required.

The sketch showing the layout (not to scale) of the cantonment is given in **Figure 3.2**. The cantonment area is divided into 15 Zones, which are serially numbered from 1 to 16, excluding the number 13. Based on the work load; source of water supply, plan of sewage disposal, and common road network, these zones are further grouped into four sectors.

Zonal accommodation including internal service. The accommodation, planned zone-wise, is as follows:

Exhibit 3.7

Construction of Education Buildings: Task Matrix with Duration

S. No.	Activity	Code	Primary School	High School	K. G. School	Nursery School
1.	Excavation and footing	EF	3	3	2	2
2.	Stub column and plinth beam	PB	3	3	2	2
3.	Plinth filling	PF	2	2	2	2
4.	Ground floor slab	GS	3	3	2	2
5.	Ground floor column	GC	2	2	2	2
6.	F. F. Slab and beam Wing I	FS	3	4	3	3
7.	Roof structure URF Wing I	RS	4	4	0	0
8.	First floor Wing II	FS	3	4	0	0
9.	Foundation portals Wing II	FP	3	3	0	0
10.	Construction Portals II	CP	4	4	0	0
11.	Gymnasium slab Wing II	SC	4	3	0	0
12.	Block work	BW	4	4	1	1
13.	Pipes/conduit and frames	DW	3	3	1	1
14.	Internal Plaster	IP	4	4	2	2
15.	AC ducting and piping	AC	2	2	6	6
16.	Roof treatment	RT	2	2	2	2
17.	Screed and wiring	SC/EW	2	2	2	2
18.	External plaster	EP	2	2	2	2
19.	Tiling	TL	3	3	2	2
20.	Preliminary paint	PT	3	3	2	2
21.	A.C. equipment installation and testing	AE	2	2	2	2
22.	C and J metal work	CJ	4	3	2	2
23.	Fitting and fixtures	FF	4	3	2	2
24.	Final paint and completion	CM	4	4	2	2

- Unit accommodation other than married (OTM): Zones 1, 2, 3, 4, 8, 9, 10, 11, 12, 14, 15, and 16. Each zone has a major unit or its equivalent number of smaller units located in it;
- Married accommodation (Md): Zones 7A, 7B, 7C, 7D, 7E, and 7F;
- Accommodation for construction staff: Zone 5;
- Cantonment hospital: Zone 4; and
- Cantonment market: Zone 6.

Figure 3.2

Zonal Layout of Cantonment Project

Legends—
1. Roads shown thus
2. Zonal Boundary thus
3. Sector Boundary thus

Sector 'A'
Zone 10
Zone 7E
Zone 12 Zone 12
Zone 9
Sector 'B'
Zone 7D
Zone 8
Zone 7C
Zone 5
Zone 6
Zone 7A
Zone 4
Zone 14
Zone 15
Zone 7B
Sector 'C'
Zone 16
Zone 1
PWD Road
Sector 'D'
Zone 3
Zone 2
& 7F
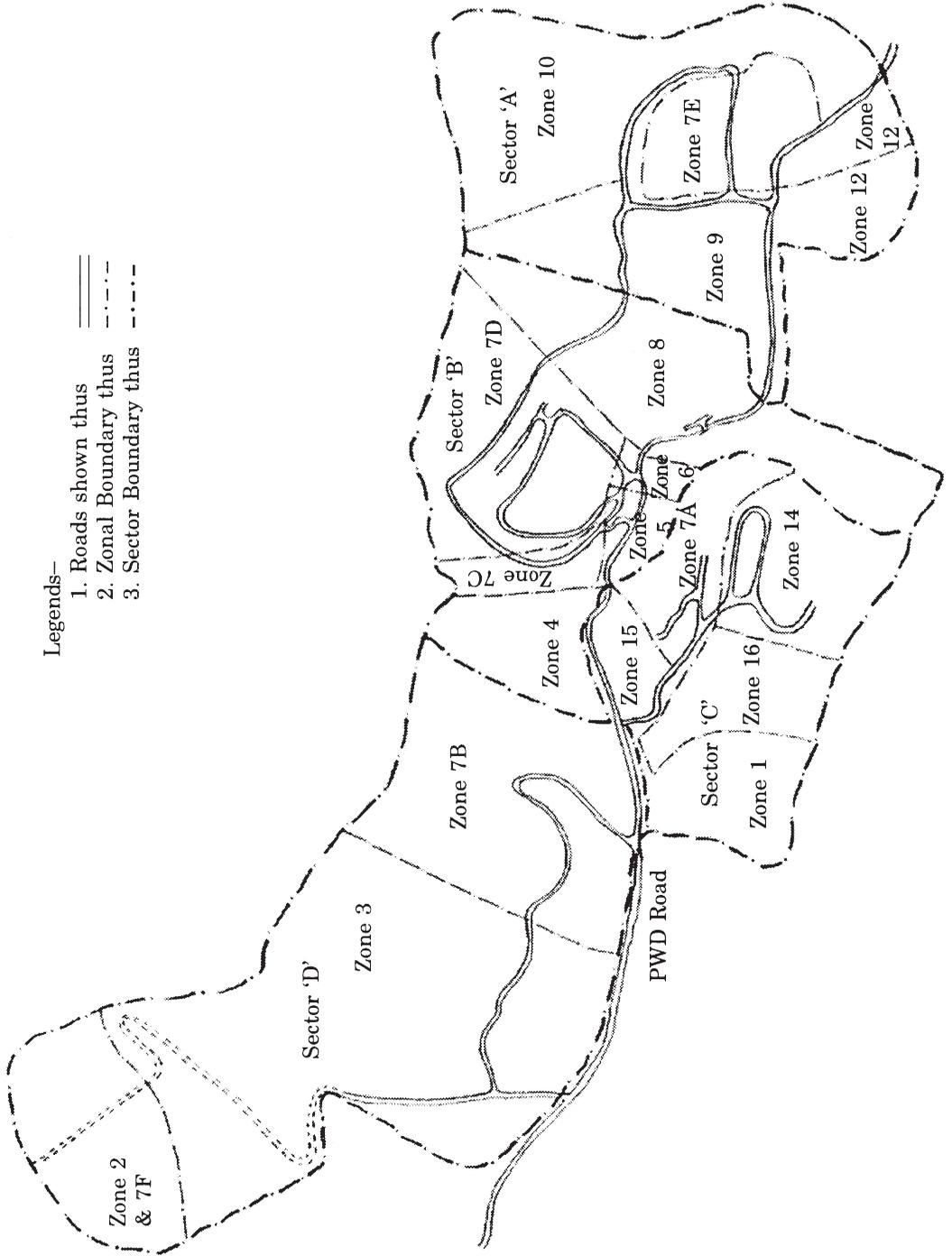
The sector-wise location of the zones is shown in the **Exhibit 3.8.** Proceeding similarly, each zone is further subdivided into sets of adjoining buildings.

Inter-sector external services. These services include roads, power supply, water supply, sewage disposal, area drainage, and arboriculture. These can be further sub-divided into inter-sector,

Exhibit 3.8

Sector-wise Location of Zones in a Cantonment Construction Project

Cantonment Construction Project

| Project Preliminaries | Sector A | Sector B | Sector C | Sector D | External Services |

OTM Zones 9, 10, 11 & 12 — Md Zones 7E

OTM Zones 4, 5, 6, & 8 — Md Zones 7C, 7D, & 5

OTM Zones 1, 14, 15, & 16 — Md Zones 7A

OTM Zones 2 & 3 — Md Zones 7B & 7F
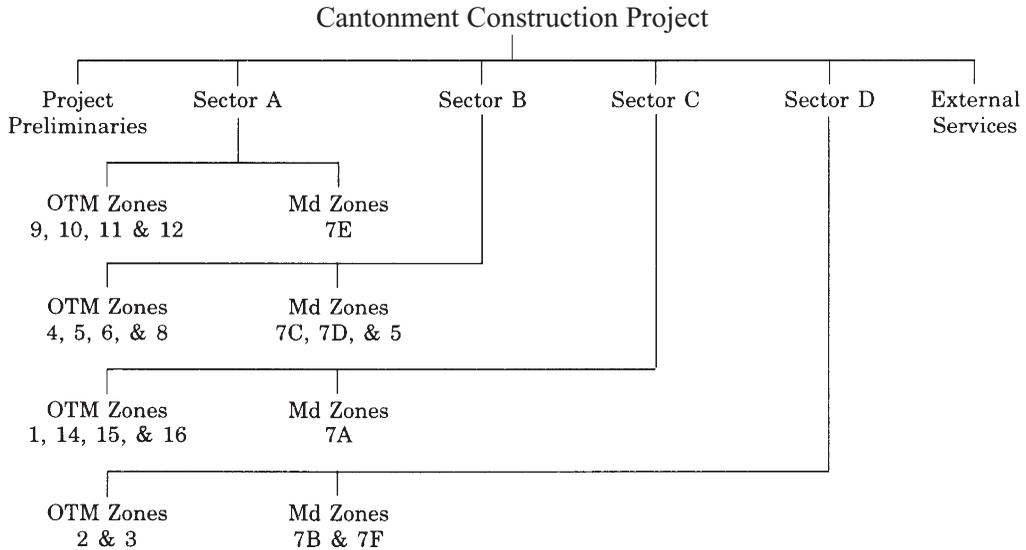
inter-zonal, and the zonal works. The work breakdown of the inter-sector service tasks is shown in **Exhibit 3.9**.

The tasks involved are outlined below:

1. **Roads.** The main road runs through the centre of the cantonment. There are a number of other roads, which connect different zones.
2. **Electrification.** The main source of electric supply is from the hydel department. The hydel power is received at the receiving station in Zone 1. It is then transmitted to the various zones by HT transmission line. There are 17 substations, which step down the high voltage to 440 volts and distribute it to the various zones by the LT lines. The power house, housing three generating sets, caters to important installations in an emergency.
3. **Water supply.** The main source of water supply is a stream. An irrigation channel connects this stream to the water treatment plant. The treated water is pumped to six water reservoirs, which are distributed to the various Zones as follows.

   - Three water reservoirs: for Zones 9, 10, 11, 12 and 7E.
   - One water reservoir: for Zones 5, 6, 8, 7C and 7D.

Exhibit 3.9

Inter-sector External Services

```
Inter-sector External Services
├── Roads
│   ├── Main Road
│   └── Inter Zonal Roads
├── Utilities
│   ├── Power Supply
│   │   ├── Installations
│   │   │   ├── Receiving Station
│   │   │   ├── Power House
│   │   │   └── Sub-stations. 1 to 14, 16 & 17
│   │   └── HT Feeders
│   ├── Water Supply
│   │   ├── Treatment Plant
│   │   ├── Pump House
│   │   ├── Water Reservoirs
│   │   └── Water Mains
│   │       ├── Rising Mains
│   │       └── Gravity Mains
│   └── Sewage Disposal
│       ├── Treatment Plant
│       ├── Oxidation Ponds
│       └── Trunck Mains
├── Area Drainage
└── Arboriculture & Landscaping
```

- One water reservoir: for Zones 14, 15, 16 and 7A.
- Two water reservoirs: for Zones 1, 2, 3, 4, 7B and 7F.

4. **Sewage disposal.**   It is based on the oxidation-pond method and is organised as follows:

   - The trunk sewer from Zones 9, 10, 11, 12 and 7E are connected to the oxidation pond in Zone 12.
   - The trunk sewer from Zones 4, 5, 6, 7D and 8 terminates in the oxidation pond in Zone B.

5. The trunk sewer from Zones 7A, 14 and 15 are also connected to another set of oxidation ponds in Zone 8.

6. The trunk sewer from Zones 1, 3 and 7B are connected to oxidation ponds in Zone 1.

   - All other Zones are connected with separate septic tanks. Area drainage and arboriculture. These are planned on area basis.

7. **Area drainage and arboriculture.** These are planned on area basis.

Cantonment projects work-breakdown structure. The Work Breakdown Structure down to the task level developed for this programme is shown in **Exhibit 3.10**.

Exhibit 3.10

Contonment Construction Project: Work-breakdown Structure
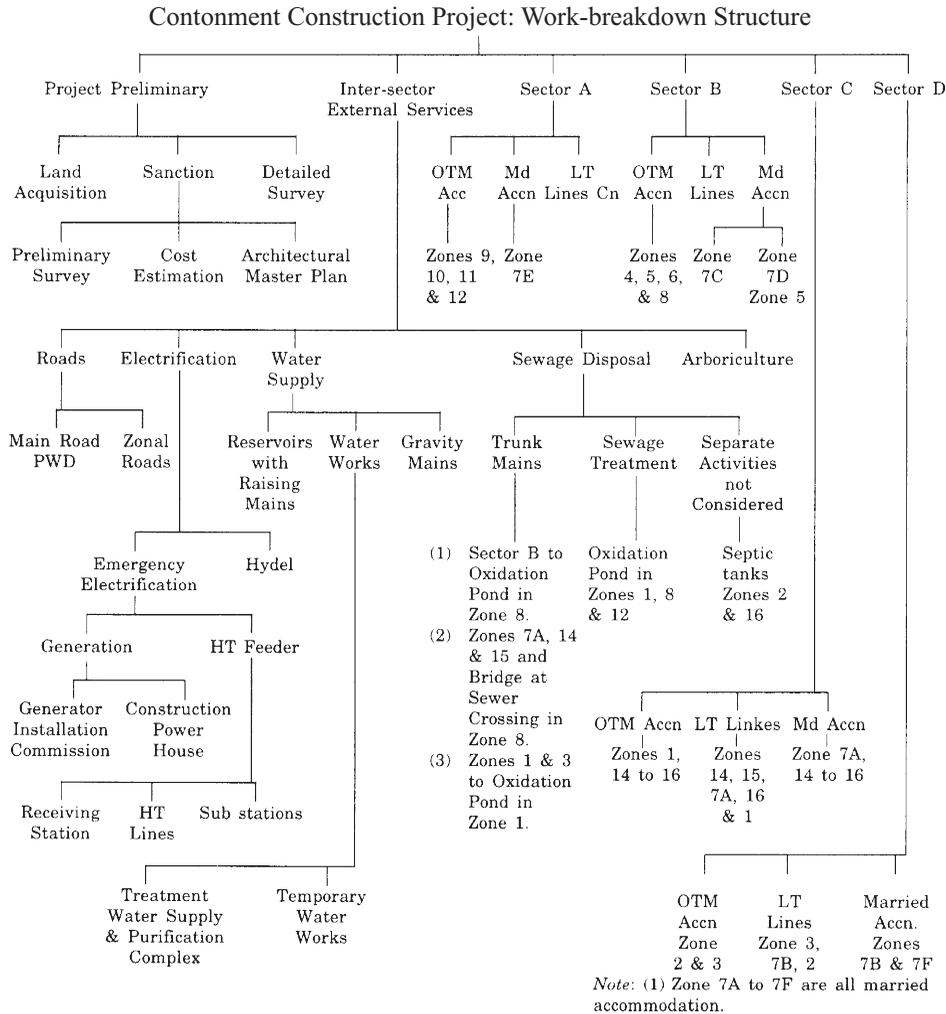
The zone accommodation was split into one or more part(s), broadly conforming to the above grouping in order to derive the list of tasks for each zone. This WBS was used for planning long duration programme with budget constraints.

3.2.6   Building Work Breakdown Templates

3.2.6.1   CI/SfB construction index manual

Background.   The CI/SfB Construction Index Manual, originally published in 1976 by the RIBA Publication Ltd, London, is primarily designed for use in project information and related applications, such as preparation of bills of quantities and establishing the performance accounting linkages.

The CI/SfB system is internationally recognised. It originated in Sweden in 1974 and was initially developed for coordinating the building processes. In 1952, it was adopted by the International Congress for Building Documentation (CIB) for standardising the classification and filling system of documents.

RIBA Publishing is the publishing arm of the Royal Institute of British Architects. With such avast experience, they have provided a range of publications for the day-to-day information needs of Architects, Designers, and Construction Professionals. These publications include contracts, forms, agreements and guidance.

Work package.   The construction elements in CI/SfB (extract in **Table 3.4**) represent the overall process of building construction, beginning with the site development and proceeding vertically down to the external utility services.

Table 3.4

Primary Division of a Building

Code no.	Primary Division	Basis of Grouping Within Division
(00)	Site development	Information relating to external site development works.
(10)	Sub-structures	Foundation work below grade
(20)	Super-structure primary elements	Load bearing structural elements above grades
(30)	Super-structure Secondary elements	Non-load bearing elements
(40)	Finishes	Exposed surface treatment
(50)	Mechanical services	All piping and ducting systems including materials and equipment
(60)	Electrical services	All wired system, materials and equipment
(70)	Fixed equipment	All fixed equipment, components and fixtures in a building
(80)	Moveable equipmentv	Alvl moveable equipment components and furnishes in a building
(90)	External services	All services not within the enclosed limits of the buildings

Table 3.4 matrix depicts primary divisions in the first column. Their corresponding sub-divisions are reflected horizontally against each of them in CI/SfB.

Generally, each primary division can represent the work package of small projects, whereas for large package, each sub-division or its further breakdown may have to be used to denote a work package. These sub-divisions are shown in **Table 3.5**.

Activities. In CI/SfB, the primary divisions are further split up horizontally into sub-divisions or activities. For example, sub-division 21 represents the external wall (load bearing), while sub-division 43 stands for the floor finishes. Further sub-division breakdown leads to the inter-connected activities. For instance, roof (27) is broken up into flat roof (27.1), pitched roof (27.2), and folded plate roof (27.4), etc.

3.2.6.2 Construction Specifications institute (CSI), USA specifications

CSI has brought out significant publications to introduce uniformity in construction documents, particularly in Construction Specification. The 50 divisions' specifications groups in a standardised sequence are being widely used by the construction industry in the US. It finds application in organising data, developing method statements, arranging project contracting manuals, and writing specifications. Master Format of CSI is the specifications-writing standard for most commercial building design and construction projects in North America. It lists titles and section numbers for organising data about construction requirements, products, and activities. Updates to Master Format are made annually. For further information about building specification of CSI, visit www.csinet.org

❑ 3.3 ACTIVITY DURATION ESTIMATION

3.3.1 Activity Duration Definition and Its Implications

Duration of an activity is defined as the expected economical transaction time that is required to perform an activity according to the specified execution method. The estimation of this time is based upon the specified practices that are carried out in an organised manner under the normal prevailing conditions. Moreover, the preferred choice for doing its assessment is by the person responsible for its performance. This definition of activity duration has many implications. These are given in subsequent paragraphs.

Duration is transaction time. The transaction time of an activity is the time taken to change from one state to the next within the system. In other words, duration is the time delay incurred in moving from one event to its succeeding event. Generally, smaller the level of activity details, the better its duration assessment. In the long run, during the progress of a project, plus and minus variations in activity duration tend to get adjusted.

It may be noted that duration is only an assessment and may differ with the actual time, which an activity take for its transaction. The methods used for assessment of the duration are one time and three time estimates. These methods are explained in Section 3.3.2.

Table 3.5

CI/SfB Manual Main Content with Codes

CI/SfB Table 0: Physical environment	**(4-) Finishes to Structure**

1	Utilities, civil engineering facilities		(41) Wall finishes, external
2	Industrial facilities		(42) Wall finishes, internal
3	Administrative, commercial, protective service facilities		(43) Floor finishes
			(45) Ceiling finishes
			(47) Roof finishes
4	Health, welfare facilities		(48) Other finishes to structure
			(49) Parts, accessories, etc. special to finishes to structure elements
5	Recreational facilities		

(5-) Services, mainly piped, ducted

6	Religious facilities	
7	Educational, scientific, information facilities	
	Residential facilities	(52) Waste disposal, drainage
8	81 Housing	(52.1) Refuse disposal
	87 Temporary, mobile residential facilities	(52.5) Rain water, surface water drainage
		(52.6) Internal drainage, above ground drainage

CI/SfB Table 1: Building elements

(52.7) Below ground drainage
(53) Liquids supply

(1-) Ground, substructure

(53.1) Cold water supply
(53.3) Hot water supply

(11)   *Ground*

(54) Gases supply
(54.1) Fuel gas supply

(13)   *Floor beds*

(54.2) Vapour supply
(54.4) Medical, industrial gas supply

(16)   *Retaining walls, foundations*

(55) Space cooling
(56) Space heating

(2-) Structure, primary elements, carcass

(56.4) Central heating: hot water, steam distribution

(21)   *Walls, external walls*

(56.5) Central heating: warm air distribution

(22)   *Internal walls, partitions*

(56.6) Central heating: electrical distribution

(23)   *Floors, galleries*

(56.8) Local heating

(24)   *Stairs, ladders*

(57) Air conditioning, ventilation

(27)   *Roofs*

(58) Parts, accessories, etc, special to piped, ducted service elements

(28)   Building frames, other primary *elements*

(28.8)   *Chimneys*

(29)   Parts, accessories, etc

(3-) Secondary elements, completion of structure

(6-) Services, mainly electrical

(31)   Secondary elements to walls, external walls

(31.4)   Windows

(61) Electrical supply
(62) Power

(31.5)   Doors, doorsets, frames

(63) Lighting services
(64) Communications

(35)   Suspended ceilings

(66) Transport

(37.4)   Rooflights

(38)   Balustrades, barriers

Duration is assessed based on specified execution method.   The choice of the method of activity execution depends upon the past experience, market availability of appropriate resources, available resources, and the cost-benefit analysis of the various execution methods of. The first step in estimating duration is to develop the methodology for execution based on current practices. Further this method of execution may undergo a change with the passage of time or with improved techniques that may alter the activity duration in due course.

Duration is assessed based on resources earmarked.   The duration of an activity depends on the volume and the nature of resources earmarked for execution. The resources, such as men, machinery and materials are required for the execution of each activity. The typical resource planning norms that can be used for preliminary estimation of major item of resources are dealt with in Chapters 7, 8 and 9.

Duration is economical transaction time.   The assessment of expected time should be based on the most economical method of activity execution under the prevailing working conditions, by using the available or earmarked resources.

   Consider a job involving 50 cubic meter of manual excavation over an area of 15 × 6 m. It is possible to organise work by employing 18 men for one day in two shifts, or three men for five days; or four men for four days to complete this task. If each man is paid $5.00 per day, and assuming that tools required for digging are brought by the workers, the time for completion of excavation and the corresponding labour costs for this activity can be tabulated as follows:

   The duration for this activity corresponding to the least cost of execution ($75) should be taken as three days. It may be noted that the duration of an activity is correlated with time and its cost. The time and cost at the least cost point is termed as normal time and normal cost of the activity.

Duration is estimated in terms of predetermined units of time.   The unit of time can be a month, a week, a day, or even an hour. The considered unit depends upon the plan type. The guidelines given below may be adapted for selecting the unit of time for assessment of duration of activities in the following:

Completion Time (Day)	Manpower Employed	Cost ($)
1	18	90
2	8	80
3	5	75
4	4	80

- Project Summary Schedule: Months or weeks
- Project Master Schedule: Weeks
- Detailed Work Programme: Working days or hours

The following conversion factors may be used for converting from one unit to another.

- Working hours in a day: 8 hours
- Working days in a week: 5 or 6 days
- Weeks in a year: 52 weeks

All activities in the network or schedule use same unit of time.   The duration assessed in weeks includes weekly holidays but excludes other holidays and non-productive period. Further, the seasonal and weather uncertainties are not considered; these are taken care of at the time of scheduling stage. Overtime is also not considered unless it is a standard practice.

The assessed duration estimate is expressed in terms of unit of time, in the nearest whole number.

Duration estimation is based on current practices.   This implies that the estimation is based on the present knowledge of the transaction method in an economical way; it may undergo a change with the passage of time or with improved techniques.

Duration estimation is based on work being carried out under normal prevailing site conditions.   This implies that estimation is based on the method of work under normal working conditions at the site, using economical resources. Adjustments for time delaying factors, like rainy season and bad weather are considered at the time of work and resource scheduling (refer **Chapter 6**).

Duration estimation methods presuppose that activity is performed in an organised manner.   Working in an organised manner implies breaking down the activity into elements, matching optimum resources for each element, laying down a systematic method of execution, and specifying objectives and responsibilities, so that the task is performed efficiently and enthusiastically. Duration is assessed preferably by the person responsible for its performance. This makes the duration estimate realistic and meaningful.

3.3.2   Duration Estimation Methods

Generally, any of the three methods are employed for assessing the duration of construction activities. These are termed as one-time estimate, three-time PERT estimate, and non-linear distribution (e.g. trapezoidal) estimate.

One-time estimate.   The estimation of duration is based on one or more of the following.

- Data planning;
- Past experience on execution of a similar project; and
- Average time assessed by a group of executives.

Example: In excavation of 3,000 cu. ft of common earth, if output of a man is taken as 100 cu. ft per day and six men can be effectively employed on the job, the duration of the activity would be five days.

In most of the construction work, it is generally possible to assess the duration of an activity with reasonable certainty by using experience or the departmental data planning. The one-time estimate

for activity durations is used in these projects. Further, the one-time estimate is task- oriented and the activity duration can be correlated to the cost and the resources employed. The method of the one-time estimate is simple and can easily be followed by all the concerned parties along with the planning or execution of construction works.

Three-time PERT estimate.   When the exact duration of an activity, like research and development, is not certain, the three-time estimate is used to compute its expected duration. The following relation is used to calculate the expected duration of such an activity:

$$T_e = \frac{T_o + 4T_m + T_p}{6}$$

Where, T_e = expected completion time
T_o = optimistic time, assuming that everything goes extremely well with no delays
T_p = pessimistic time, assuming that everything goes wrong
T_m = most likely time, assuming normal conditions

Example: Let us take the activity of sanctioning a government project. It has to pass through many channels and depends upon many factors. Let us assume that the sanction is most likely to take 8 weeks, and if all goes well, the earliest it can happen is 6 weeks, but in any case, it will certainly come through in 16 weeks. The expected duration of the activity can then be calculated as follows:

$$T_o = \frac{6 + (4 \times 8) + 16}{6} = 9 \text{ weeks}$$

The three-time estimate can effectively be used in certain areas of construction projects where time is the main criteria and the resources employed are of secondary consideration. Some of these are as follows:

- The planning of projects especially, at the feasibility stage;
- The skeleton networks enclosed with the tender documents;
- The contracted works, where time is the main consideration for the management; and
- The complex structures, where the exact duration estimate is difficult to assess.

The analysis of networks using the three-time estimation is based on probabilistic methods, which are covered in **Chapter 4**.

Non-Linear distribution estimate.   The one-time activity duration estimation methodology, given above, assumes average daily uniform manpower (or effort) of work throughout the execution of activity. But execution of some activities may need effort in a non-linear pattern. Such non-linear distributions may follow triangular, trapezoidal, binomial, beta, gama, normal or other

pattern. In such cases, the activity duration estimation needs to be modified accordingly. Some of the non-linear probability distribution are given below (see **Table 3.6**) that are used to convert this distribution into one-time expected or mean value.

Formulae are approximations only. Readers may refer to standard books on statistics to understand

Table 3.6

Probability Distributions Approximates Statistics for Simplifying Calculations

Statistics	Normal	Beta	Triangular	Uniform
Expected Value or mean	$(a + b)/2$	$(a + 4m + b)/6$	$(b + m + a)/3$	$a + (b - a)/2$
Variance s ^{2}	$(b - a)^2/36$	$(b - a)^2/36$	$[(b - a)^2 + (m - a) * (b - m)]/18$	$(b^3 - a^3)/[3*(b - a)]- (b - a)^2/4$
Standard Deviation, s	$(b - a)/6$	$(a - b)/6$	$\sqrt{v}$	$\sqrt{v}$

Note: a = Optimistic value, b = Pessimistic value, m = Most likely value, v = variance

these probability distributions and estimation formulae for calculating their mean and standard deviations.

The non-linear probability duration estimate are used in those projects, which involve high degree of risk, like oil exploration (for further reading, refer **Chapters 16** and **17**). This method of estimation is employed in GERT networks, which are rarely used in construction projects.

3.3.3   Duration Estimatiotn Procedure

The various stages in duration estimation of a construction activity can be identified as follows:

- Decide the method of execution;
- Estimating the quantity of work involved;
- Identify the resources required;
- Assessing the effective employment of resources;
- Estimating the activity completion period usingt estimated resources;

$$\text{Completion Period} = \frac{\text{Quality}}{\text{Output per unit of resource} \times \text{Resource earmarked}}$$

- Rounding off the completion period to nearest value after making reasonable contingency allowance; and
- Use the three-time PERT or a non-linear estimate, where it is not possible to predict reasonable activity duration by one-time method and then convert it into one-time estimate.

Example: Highway pavement construction duration estimation. Calculate the duration of road pavement construction activities for one KM road stretch of service road. The quantity of work, the output of each equipment team, and the equipment team composition are shown in the table below. The equipment team available with assessed output is given in **Table 3.7**.

Table 3.7

Equipment Team Output

S. No.	Equipment Team Nomenclature	Output (m³/day)	Available Team Equipment
1	Clearing , Grubbing and E/W cutting/ exc by dozer/excavator	720/10 hrs.	Dozer (D80), Exc., Tipper-3
3	E/W Emb/filling	720/10 hrs.	Dozer (D80), MG, Vib Roller (10 tons),W. Tanker(6KL)
4	Sub-grade	720/10 hrs.	Dozer (D80), MG, Exc.Vib Roller (10 tons), Tractors 50HP (2)
5	GSB	600/10 hrs.	MG, Vib Roller (10 tons), W. Tanker (6KL)
6	WMM	500/8 hrs.	WMM (2x200 TPH), Paver (100 TPH)
7	DBM and BC	500/8 hrs.	HMP 2x120 TPH, Pavers (2x100 TPH), Rollers 2 each of type Vib, Tandem, Smooth Wheel, Tippers 5.5 cum

Note: Output of road pavement construction equipment is given in **Table 3.8**. These can be suitably modified based on available equipment.

3.3.4   Activity Resources Estimation

The construction activity accomplishment process combines resources like men, materials, and machinery. The duration of an activity and the resources required are interlinked. For example, the activity of placing concrete in the foundation of a large building can be done manually or using crane and bucket arrangement, or pumping by concrete pumps or transporting by a conveyor system. The time and cost for each of these methods will differ accordingly. Similarly, the time and manpower required for wall shuttering will depend upon the type of shuttering used from the available choices of custom-built steel wall forms and the conventional timber-plywood steel props support system. In short, it is the method of production and the time available that dictates the resources required for accomplishment of an activity.

In the initial stages of duration estimation, it is necessary to make a preliminary assessment of the resources of men, machinery and materials, which are required for the execution of each activity within assumed/stipulated duration. This assessment is used to forecast resources required, develop a time schedule within resource constraints, and evaluate the connected costs.

Table 3.8

Equipment Teams Available and Duration Estimation

S. No.	Nature of Work	Work Quantity (CM)	Eqpt. Team Output m³/day	Eqpt. Team Days	Eqpt. Teams Available	Dur. (Days)
A	**B**	**C**	**D**	**E = C/D**	**F**	**E/F**
1	Clearing , Grubbing and E/W cutting/exc	11931	720/10 hrs	16	2	8
3	E/W Emb/filling	12719	720/10 hrs	18	2	9
4	Sub-grade	20430	720/10 hrs	28	2	14
5	GSB	5337	600/10 hrs	9	1	9
6	WMM	6158	500/8 hrs	12	1	12
7	DBM	4183	500/8 hrs	8	1	8
	BC	1921	500/8 hrs	4	1	4

The preliminary estimate of resources needed to accomplish an activity can be made by using the planning norms developed from the past experience of companies or the published literature, suitably modified to conform to project environment.

The resource planning norms include the following:

- Workers output norms;
- Plant and machinery output norms; and
- Materials quantity estimation and wastage norms.

The typical resource planning norms that can be used for preliminary estimation of major item of resources are dealt with in **Chapters 7, 8** and **9**.

The methodology for costing of resources and activities is covered in **Chapter 11**.

Exhibit 3.11 shows the Foundation Construction Sub-Project: Activity-wise Workers' Requirement and Cost Estimate for One Foundation Module are tabulated in **Exhibit 3.11**. **Exhibit 3.12** illustrates the Construction Sub-Project: Major Materials Requirement and Cost Estimate for One Foundation Module.

3.3.5   Human Side of Activity Duration Estimation

Initially, in analysing the duration estimators, the followed approach includes calculation of expected duration estimate corresponding to around 50% confidence level using one-time, three-time or other methods. Thereafter, they add contingency time to allow for unforeseen safety/reserves ex-

Exhibit 3.11

Foundation Construction Sub-Project: Activity-wise Workers' Requirement and Estimation for One Foundation Module Construction

No.	Activity	Unit	Quan-tity	Duration Hours	Direct labour crew		BOQ Code
					Skilled	Unskilled	
1.	Layout for excavation	-	-	4	-	2	1-1
2.	Excavation with machines	CM	400	8	-	1	"
3.	Base preparation	SM	360	16	4	10	"
4.	Anti-termite at base	SM	362	4	-	2	A1-4
5.	Polythene sheeting	SM	362	6	-	3	A1-6
6.	Shuttering for blinding	RM	90	8	2	2	A1-7
7.	Placing concrete M-100	CM	18	18	4	5	A1-6
8.	Layout for raft	-	-	4	1	2	A1-8
9.	Shuttering for raft	SM	22.5	8	2	2	"
10.	Reinforcement for raft	MT	6.066	32	10	5	A1-11
11.	Raft concreting M-250	CM	88.14	5	5	6	A1-8
12.	Curing raft	-	-	4	-	1	"
13.	Bitumen coating raft sides	SM	362	3	2	3	A1-5
14.	Layout for plinth wall	-	-	4	-	2	A1-8
15.	Wall shuttering	SM	485	48	0	8	"
16.	Wall concreting M-250	CM	43.78	3	5	6	"
17.	Deshuttering	-	-	16	8	8	"
18.	Curing wall	-	-	8	-	1	"
19.	Bitumen coating wall and raft	SM	319	3	2	3	A1-5
20.	Back filling	CM	120	8	-	4	A1-2
21.	Plinth filling	CM	305	16	-	8	A1-3
22.	Anti-termite under GF slab	SM	172	2	-	2	A1-4
23.	Polythene sheeting	SM	225	3	-	2	A1-6
24.	Shuttering for GF slab	SM	11	8	1	1	A1-9
25.	Weld mesh fixing	MT	0.651	8	4	2	A1-10
26.	GF concreting M-250	CM	28.34	2	5	6	A1-9
27.	Curing GF slab	-	-	8	-	1	"
28.	Total manhours				1202	1304	
29.	All-in rate per manhour				$ 1.50	$ 1.25	
30.	Direct Labour Cost				$ 1803	$ 1630	

pected corresponding to around 80–95% confidence level to make it a highly probable performance target. Thus, traditional duration estimation approach includes hidden safety factors in each activity to cater for Murphy's Law according to which "if anything can go wrong, it will." This makes executives feel comfortable, but it results into many harmful consequences, such as:

1. Parkinson's Law comes into action. The work effort expands to accommodate the additional time. People simply adjust the level of effort to keep occupied for the entire duration.
2. Level of effort generally, follows the "Student Syndrome". Little effort is made by the student during the initial days of assigned homework and when the safety period is over, work starts with high speed sometimes leading to overruns from the original estimated date for submission of the assignment.
3. It erodes hidden safety reserves. The project is denied the benefit of the safety time, included in activity duration estimate, which would have yield a positive variance, if the work is executed at a high speed as done during the final days of "Student Syndrome". In fact, excess activity duration wastes safety time, which is catered to protect against effects of Murphy's Law.

In 1997, Dr. E. M. Goldratt postulated a new approach to minimise time and cost overruns that address both the human aspect and the technical approach in project management. It is based on the originator's bestselling novel, Critical Chain. This technique is called Critical Chain Project Management (CCPM) and it is outlined in **Chapter 16**.

❑ 3.4 ACTIVITY COSTS AND BOQ WORK-ITEM RELATIONSHIP IN CONTRACTED PROJECTS

3.4.1 Activity Cost Classification

In general, the term cost implies expenditure that is incurred in monetary terms by a person or an agency to acquire a product or a service or to accomplish an objective. For a given product, the expenditure incurred or the money spent by the customer to acquire it, the manufacturer to produce it, and the retailer to sell it, is not the same. The cost of an item is related to the purpose for which it is incurred; it varies when it passes through various agencies.

For example, suppose a customer purchases an apartment from a Realtor for one-million U.S. dollars. The total money paid by the Realtor to acquire it from the builder is $950 000, while the production cost incurred by the builder for the land and construction is US $850 000. In each case, the cost is related to the specific purpose or activity for which it is incurred, and the cost associated for accomplishment of each activity becomes its cost objective.

In other words, the cost objective represents the cost, which a person or agency has decided to pay for fulfillment of a specific purpose. In particular, the term cost, when singly used in this book, stands, for the production cost. The cost classification varies with the purpose. In general, the activity costs can be classified as follows.

Exhibit 3.12

Foundation Construction Sub-project: Major Materials Requirement Estimate for One Module Foundation

| S. No. | Activity | Unit | Quan-tity | Concrete | | Rebar steel | | | Bitm KG | Trmt LTR | PVC Sht SM | Soil Import CM |
				M100 CM	M250 CM	Tor MT	Mesh MT	Wire KG				
1.	Layout for excavation	-	-									
2.	Excavation with machines	CM	400									
3.	Base preparation	SM	360									
4.	Anti-termite at base	SM	362							75		
5.	Polythene sheeting	SM	362								400	
6.	Shuttering for blinding	RM	90									
7.	Placing concrete M-100	CM	18	18								
8.	Layout for raft	-	-									
9.	Shuttering for raft	SM	22.5									
10.	Reinforcement for raft	MT	6.066			6.066		60.66				
11.	Raft concreting M-250	CM	88.14		88.14							

No.	Activity	Unit									
12.	Curing raft	-	-								
13.	Bitumen coating raft sides	SM	362					91.2			
14.	Layout for plinth wall	-	-								
15.	Wall shuttering	SM	485								
16.	Wall concreting M-250	CM	43.78	43.78							
17.	Deshuttering	-	-								
18.	Curing wall	-	-								
19.	Bitumen coating wall and raft	SM	319					103.4			
20.	Back filling	CM	120								
21.	Plinth filling	CM	305								80
22.	Anti-termite under GF slab	SM	172								
23.	Polythene sheeting	SM	225							250	
24.	Shuttering for GF slab	SM	11								
25.	Weld mesh fixing	MT	0.651			0.651					
26.	GF concreting M-250	CM	28.34	28.34							
27.	Curing GF slab	-	-								
	Total manhours		18	160.26	6.066	0.651	60.66	194.6	75	650	80
	Assessed wastage		10%	3%	3%	10%	3%	-	-	10%	15%
	Materials required		19.8	165.07	6.248	0.716	62.48	194.6	75	715	92
	Unit Rate in $		77.8	111.7	557.1	640.0	0.96	0.56	6.4	0.36	9.6
	Direct materials cost in $		1540	18438	3481	458	60	109	480	257	883

Cost Purpose	Cost Classification
1. Estimating costs	Direct and indirect costs
2. Accounting costs	Production cost and earned (sales) value

The above cost terms are outlined in the following paragraphs. These are further elaborated in **Chapter 11**.

Activity direct cost. This is the cost that can be traced in full with the execution of a specific activity. It consists of costs of direct materials, labor, equipment and other costs. For example, in the activity of roof concreting, the following direct costs would be involved.

Type of Costs	Items of Costs
Direct materials	Cost of concrete and steel
Direct labour	Cost of labour employed
Direct equipment	Cost of equipment hired for placing ready-mix concrete
Direct other expenses	Formwork hiring charges

Activity indirect cost. This is the cost that is incurred while performing an activity, but cannot be traced directly to its execution. In other words, all costs other than the direct ones fall in this category. These represent the share of supervision, general and administration costs, and are commonly referred to as overheads. Generally, the overheads charged to an activity are expressed as a percentage of its direct costs.

Activity production cost. This cost is the sum of direct cost and its apportioned indirect cost. It is built up as follows:

Cost Elements	Amount
1. Direct material costs	A
2. Direct labour costs	B
3. Direct equipment and other expenses	C
4. Direct costs (A + B + C)	D
5. Indirect costs	E
6. Production cost (D + E)	F

3.4.2 Activity Earned Value in Contracted Projects

It is the BOQ value of the work done in a contract, which the client is committed to pay for the satisfactorily completed works. In contracted works, Earned Value is the sale price, calculated at contract rated, which the owner has budgeted for payment to the contractor for the work done.

Earned value or sales prices for various items of work are fixed and these are listed in the Bill of Quantities (BOQ). As an example, **Table 3.9** shows an extract from the Bill of Quantities (BOQ), for the foundation work of a residential building complex (with actual data modified). In the BOQ, the sale price is generally expressed in units of the work item. But for forecasting and monitoring this price or earned value, it is necessary to compute the sales price, preferably activity-wise.

Table 3.9

Bill of Quantities: Foundation of a Residential Building (Original Modified)

Item No.	Description	Qty	Unit	Rate ($)	Amount ($)
A. 1	Excavation in foundation includes disposal of earth within the work site, leveling and dressage and compaction of final source.	44,400	M³	5.00	222,000
A. 2	Backfilling and compaction around foundation in layers not exceeding 30 cm with excavated earth	13,320	M³	5.00	222,000
A. 3	Earth filling and compaction in plinth with approved soil in layers not exceeding 30 cm level	33,855	M³	20.00	677,100
A. 4	Anti-termite treatment for bottom and sides of foundation plinth wall as per approved manufacturer's specifications	59,274	M²	7.50	444,555
A. 5	Painting with 2 coats of bitumen paint to foundation sides and plinth wall surface	75,591	M²	2.45	185,198
A. 6	Laying of polythene sheet 1000 G as separator between earth and concrete, and earth ad ground floor slabs	65,157	M²	1.00	65,157
A. 7	75 thick blinding concrete Grade M-100 in foundation with sulphate resisting cement	1,998	M³	95.05	189,910
A. 8	Reinforced concrete Grade M-250 in foundation and plinth walls with sulphate resisting cement including inserts, formwork and including expansion joints as necessary but excluding reinforcement	14,643	M³	163.50	2,394,150
A. 9	Same as Item 1.8, but for ground floor slab	3,146	M3	144.95	455,975
A. 10	Mild steel weld mesh reinforcement as per BS 1221 for ground floor slab	72.26	T	1,518.10	109,691
A. 11	High strength deformed bars reinforcement as per ASTM 1-615 Grade 60 or equivalent	673.33	T	1,095.00	737,292

This computation is carried out by developing a correlation between each work item and activity. By breaking down an item of work into activities, or subdividing an activity into items of works, as the case may be.

Example 1:   This example illustrates the splitting up of sales price of the BOQ work-item No. 8 into work package sales price.

Let us consider the BOQ item No. A8 in **Table 3.9** relating to plinth wall concreting. It represents the concrete M-250 in the plinth wall of a building module of the repetitive-type residential build-ing construction complex. This work item can be broken down into the sales price of connected activities of the work-package as shown in **Table 3.10**.

Table 3.10

Sale Price Breakdown of Raft Concreting Work Package

BOQ	Activity	Qty	Unit	Rate ($)	Amount ($)
A-5	Bitumen painting	362	m^3	2.45	886.90
A-8	Layout	-	-		-
A-11	Reinforcement fixing			Included in raft work package	
A-8	Shuttering	485	m^3	-	-
A-8	Concreting	43.7	m^3	163.50	7144.95
A-8	Deshuttering	-		-	-
A-8	Curing	-		-	-
Total Value	Concrete placed	43.7	m^3		$8031.85

Standard unit sales price of work package 'plinth wall' expressed in work-unit of m^3 concrete placed works out as $8031.85/43.70 = $183.80/m^3.

Example 2:   This example shows the determination of sales price of work-package representing ground floor slab of one module from the given BOQ work item.

The sales price of the work package ground floor slab in work units of m^3 concrete placed works out to $515.82 m^3, that is, $14648.42 divided by 28.34. See **Table 3.11** for details.

❑ 3.5   ACTIVITY DATABASE

An activity is defined in terms of its database. The database components include the quantified val-ues of the all the parameters that are related to the accomplishment of an activity (or a task) in the estimated time. These parameters include:

- Activity description;
- Method of execution of the activity;
- The quantity of work involved, expressed in standard units of measures;
- Activity estimated duration;
- The quantities of physical resources needed including direct labour, direct material, and direct equipment;

Table 3.11

Determination of BOQ Price of Ground Floor Slab Work Package

BOQ	Activity	Qty	Unit	Rate ($)	Amount ($)
A-5	Bitumen painting	319	m³	2.45	781.55
A-2	Back filling	120	m³	5.00	600.00
A-5	Plinth filling	305	m³	20.0	6100.00
A-4	Anti-termite treatment	172	m²	7.50	1290.00
A-6	Polythene sheeting	225	m²	1.00	225.00
A-9	Shuttering	11	m²	-	-
A-10	Weld mesh laying	0.651	Ton	1518.10	988.28
A-9	Concreting M 250	28.34	m³	163.5	4633.59
A-9	Curing	-	-	-	-
Total Value	Concrete placed	28.34	m³		$14618.42

- The estimated production direct cost including direct labour costs, direct material costs, direct equipment costs, and sub-contractor costs; and
- The budgeted cost or earned (contact) value.

In addition, an activity database also includes activity identification code (ID), predecessors, successors, start date, completion scheduled date, and imposed constraints.

Some of these parameters get defined during the activity duration estimation process; while the others are known after the planning processes of resources and cost, described in **Chapters 7**–**12**.

Activity Database Model
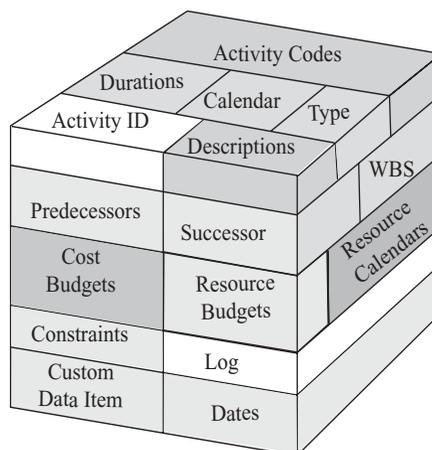
APPENDIX C

Applications of Work Breakdown Structure

❏ C.1   INTRODUCTION AND SCOPE

The work breakdown structure (WBS) of a project is one of the most valuable tools of project management. It is designed and created during the initiation and planning phase. WBS finds wide and varied applications in the various phases of a construction project from inception to close out. It forms the basis for defining the scope of work and change request, identifying activities, developing time schedule, structuring the organisation, assigning responsibilities, organising costs and budgeting, monitoring performance, codifying systems, organising data, managing information flow, closing project on completion and analysing the sources of risks.

This Appendix examines the WBS concept and definition. It outlines the typical applications of WBS in various phases of a construction project. Towards the end it outlines the characteristics of a good project work break down structure.

❏ C.2   WBS CONCEPT

Study of the project management literature reveals that the WBS definitions have under gone many successive changes from its original concept of 'task oriented family tree of activities' to the widely accepted and globally recognised PMI current WBS definition. It states that 'WBS is a deliverable-oriented hierarchical decomposition of the work to be executed by the project team to accomplish the project objectives and create the required deliverables with each descending level of the WBS. Each descending level represents an increasing detailed definition of the project work. The WBS is decomposed till the desired lowest level is reached. The desired lowest level could be upto work packages or activities. The current WBS definition has the following implications when applied to construction projects:

1. **Deliverable orientation**. The deliverable orientation includes both internal and external deliverables. The deliverable orientation implies a given configuration of deliverables and shows a unique and verifiable process, product, service or a combination of these that must be completed to achieve the specified outcome.
2. **Hierarchical decomposition**. Decomposition is a planning technique that subdivides a work scope component into meaningful smaller unit (similar to a parent-child relationship in a family), which can be easily understood, verified, and monitored.

3. **100% Rule of work scope**. This rule implies 100% of the scope of work must be included in the WBS. It means the decomposition of all deliverable is processed till the complete scope of work is linked in the WBS; and all the deliverable can be easily understood, planned, monitored, verified, and accepted. The WBS should not include any work that is not within the project scope.

Generally the project time schedules are best monitored at activity level and the costs are best monitored at the work package level. The WBS organises and defines the total scope of the project.

A WBS dictionary is a document that briefly covers each deliverable component and outlines its scope of work and it defines parent and child relationship. It may also include the other relevant information about the component database (like identification (ID), start and completion dates, estimated cost and value of work), applicable quality specifications, organisation/person responsible for accomplishment etc.

❑ C.3   TYPICAL WBS APPLICATIONS

C.3.1   Managing Project Scope

WBS is a simple basic tool that defines the entire scope of the project. WBS separates items of work intodeliverable components and establishes the relationship of the deliverables with the scope of the project tobe completed. WBS creates a deliverable oriented hierarchical top-down structure that provides the view ofthe entire project work scope. WBS contains the entire scope of work thus reducing the chances of missinga deliverable item or task. If an item is on the WBS, then it is a part of the scope of the project; otherwise itis not. WBS can be structured in a hierarchical manner or in an indented tabulated text format as illustratedin examples in **Section 3.2**.

The WBS prepared at the beginning of the project provides conceptual view of the work scope. Onmaturity, it takes the role of the project scope baseline. A matured WBS can facilitate scrutiny of work-in-progress to ensure that all works in progress are within the scope of the project. WBS can be employed tomonitor the progress of works scope. On completion of work, it can be used to verify the work accepted isspecified item of WBS and BOQ. In short, WBS is essential for the success of the project.

C.3.2   Managing Project Time Schedule

WBS is the basic input for developing project time schedule. It is the backbone for developing andmanaging the time schedule. The deliverables in the WBS are decomposed into tasks, work packages andactivities. It enables identifying, arranging and listing the project activities in a sequential order. The WBS patterns used for identifying activities are covered in **Chapter 3**. WBS simplifies time progress monitoring.The decomposition of work scope into activities facilitates monitoring of time progress. The projectschedule acts as baseline. Using schedule as baseline for time and earned value performance, the monitor can indicate time and cost status showing whether it is ahead or behind the schedule. Updated WBS acts ascommunication tool to facilitate time and cost performance reporting.

C.3.3 Managing Project Costs

WBS aids in developing a hierarchical view of cost breakdown. It helps in costing, cost planning,budgeting, accounting, monitoring and controlling costs. Such structures are used for developing a costcodification system in BOQ, Bill-of-Materials and Accounting Cost.

For accounting purposes, cost is generally assigned to each work package and the budgeted amounts arecalculated by summing up the various work packages. WBS can be coded to define each element of cost.Such an arrangement is often termed Code of Account. For the purpose of managing costs, each element ofthe WBS can best be viewed as a three-dimensional model. Three axes of this model can be represented asin **Figure C.1**.

Figure C.1

The Structure of a Project: A Three-Dimensional Cost Control Model

Control Account Database Structure
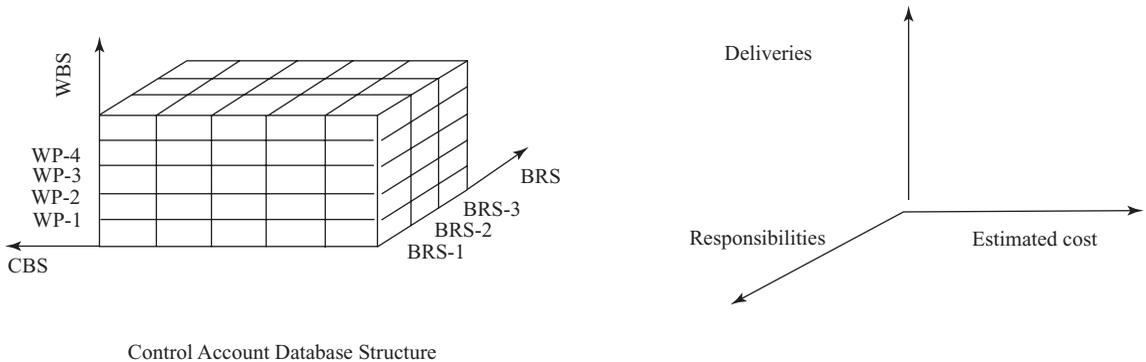
1. Estimated cost. These are further sub-divided into cost elements such as labour costs, material costs, equipment costs and other expenses.
2. Deliveries. These generally conform to work packages derived in the project work break-downstructure.
3. Management implementation responsibilities. These identify the resource person responsible-to accomplish the delivery targets within estimated costs.

C.3.4 Designing Organisation

Structuring the Organisation.   WBS indicates how the project organisation structure can be designed andhow the reporting structure can be established. Organisation Breakdown Structure (OBS) of linemanagement hierarchy (**Exhibit 1.1**) generally follows the WBS levels of sub-projects, tasks and workpackages. The guidelines for designing of the project OBS are outlined in Section 1.7.3.

Assigning Responsibilities.   WBS is cross-referred with organisational functions to define individual anddepartment assignments in the Responsibility Assignment Matrix (RAM). WBS pinpoints individualsresponsible for a given work assignment. Names of the responsible persons can be entered against eachwork element in the WBS. It also shows how project personnel relate to the rest of the project (see **Figure C.2**)

The development of responsibility assignment matrix for assigning responsibilities among the project stakeholders and the members of project team is covered in **Chapter 2**.

Figure C.2

**Organisation Breakdown Structure
Work Package, '3' and Taskforce, 'C'**
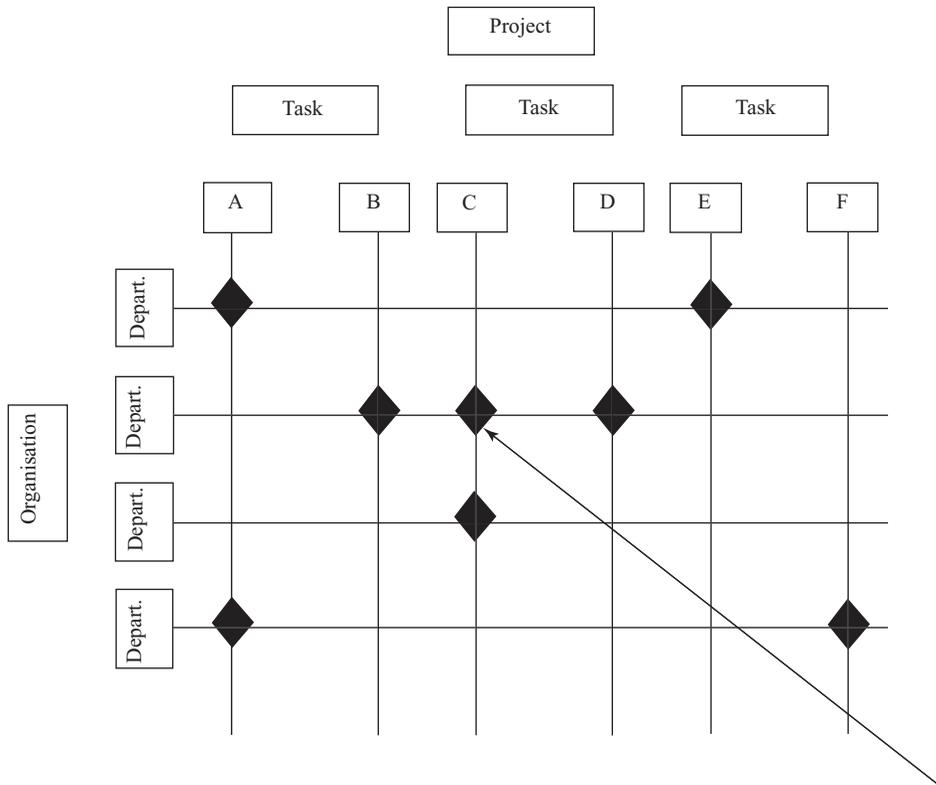
C.3.5   Data Codification and Organisation

A project organisation handles large varieties of data. This data includes activities, resources, costs and documents. The project management system is codified primarily to serve a four-fold purpose:

a. To identify the data connected with each work package and activities, as these form the data base for managing various project functions.

b. To aid in the organisation of data into various levels of WBS, management and functional units.
c. To computerize the data processing system.

Each code is made unique. In fact, an organised control of a major project is not possible without the proper codification of the project data. The code is built up by using alphabets, numerals, symbols, or a combination of these. These codes abbreviate data and expressions used in natural language into some set of predetermined string of characters. Short-length data code reduces storage space and costs. Each code is unique. In fact, an organised control of a major project is not possible without the proper codification of project data. To quote an example, foundation activities of a housing complex were codified as shown in **Table C.1**.

Example. In the Foundation Package of a Housing Project, the IDs assigned activity-wise are given in **Table C-1**.

Table C.1

Base Preparation Work Package

ID	Activities
RBFD013B11	Layout for excavation
RBFD013B12	Excavation with machine
RBFD013B13	Base preparation
RBFD013B14	Anti-termite at base
RBFD013B15	Polythene sheeting
RBFD013B16	Shuttering for blinding
RBFD013B17	Placing concrete M-100

Where,
- RBFD represents the Residential Building Foundation
- 013 is the Building Module Location Number B
- Represents the Base Preparation Work Package
- 11 to 17 are the serial number of activities

In a major project, the activity identification coding structure generally follows the work breakdown hierarchy. The coding starts from the top, it goes down from project/sub-project levels until activity level is reached. With a well-defined codification system of project variables, the project data can be arranged by WBS levels, resources, costs, departments, responsibilities, life cycle phases and so on.

Project management software provides the facility of developing a WBS dictionary in a hierarchical order. It enables organisation of deliverables in the customised format. The various modes in which data can be organised using appropriate project management software are as follows:

- WBS format;
- WBS/group by department/responsibility early vs. target bar chart for monitoring progress;

- Organisation of information at various levels;
- Early vs. target bar chart by responsibility and
- Cost category layout.

Similarly in multi-project environment, WBS facilitates the management of projects in a computer aided enterprise project management of a corporate. It is made possible by ensuring consistency as far as possible in WBS pattern, calendar, activity codes, resource codes and cost accounting codes of the projects to be managed. Organised data displays for a project developed using software are given in **Appendix F**.

C.3.6 Sources of Risks

It is said that the real risks in project management are the ones which we fail to identify. The breakdown of the work into activities in WBS enables the identification of the sources of risks activity-wise thus minimising chances of missing risk sources. Project risk sources, events identification and quantification techniques are covered in **Chapter 17**.

❑ C.4 GOOD QUALITY WBS ATTRIBUTES

There is a general understanding that WBS is the foundation upon which the project management structure stands but there is little agreement regarding the characteristics of a quality WBS. A good quality WBS must fulfill the minimum set of core attributes that should be there in all the WBS. In addition, the project specific user-related and user-specific characteristics should also be included where it is applicable. The guidelines given in the subsequent paragraphs can be followed to determine the quality of a good WBS.

C.4.1 Good Quality WBS Core Attributes

The good WBS of all the projects should have the following attributes:

- It is deliverable-oriented and has full scope of the project work including internal and external works;
- It has a coding system that generally conforms to the hierarchy;
- It has hierarchical decomposition of the work in that each level of decomposition includes 100% of the work of the parent element;
- It can be well understood and executed by the project team;
- It creates the required deliverables and its each descending level represents an increasing detailed definition of the project work;
- It is decomposed till the lowest desired level is reached;
- The lowest desired level could be upto work packages or activities;
- In general, the project time schedules are best monitored at activity level and the budget costs are best monitored at the work package level;
- It is updated regularly and the performance is communicated to all concerned; and
- It has all components listed in the WBS dictionary.

C.4.2   Good Quality WBS: Specific User Related Attributes

The Project Specific user-related attributes are in addition to the core attributes. Such characteristic of WBS include but are not limited to the following

- Decomposition of a project with uncertainty may have to be restricted to a higher level to exercise control;
- In case of high priority projects, WBS may have to be decomposed to the lowest operational level;
- WBS of some projects may need addition of special type of items like designing, procurment, contracting etc.;
- Some projects may require accountability assignment at certain levels.

C.4.3   Poorly Developed WBS Consequences

A poorly developed WBS will involve frequent changes in plan, procurement, resource induction, unclear assignments, disputes and conflicts. Such changes are bound to have time and cost overruns.

Project CPM and PERT Network Analysis

The advancements in technology and the speed of execution of modern construction projects involve inter-relationship of the voluminous interdependent activities. These projects carry the risk of schedule slippages, time overruns, inadequate decisions and contractual complications. The network analysis techniques, which were developed between fifties and sixties era, are now used as an effective management tool for planning, scheduling and controlling of complex projects.

The term *project networks analysis* is a generic term that covers all the network techniques used for planning, scheduling, and controlling of projects. The three such commonly used techniques are Critical Path Method (CPM), Program Evaluation and Review Technique (PERT) and Precedence Diagramming Method (PDM), hereafter is called Precedence Network Analysis PNA) (see **Figure 4.1**). These network techniques generate time-oriented diagram having activities organised into a logical order. Common features are that they make use of the network model for depicting the time plan of the project, apply the critical path concept for determining project duration and identifying critical activities, and, employ network analysis techniques for controlling the project-time objectives. But each of these techniques has a distinct model with a varying field of application. Experience has shown the following:

1. CPM is best suited for developing the sub-networks of sub-groups and task having activi-ties with deterministic single-time duration. The sub-networks can then be systematically integrated into a project network using the PNA techniques.
2. PERT is useful for projects involving uncertainties. In such cases, probabilistic approach of three-times is used for assessing the activity duration.
3. PNA is the commonly used technique for time planning of construction projects.
4. Graphical Evaluation and Review Technique (GERT), which includes probabilistic conditional branching and looping paths, is rarely used in construction projects and is not included in this book.

This chapter describes the CPM and PERT network analysis techniques. It covers the following topics:

Figure 4.1.

Project Networking Techniques.

Comonly Used Project Techniques

Activity-On-Arrow (AOA) Techniques

Activity-On-Nodes (AON) Techniques

CPM PERT

PNA (PDM) GERT
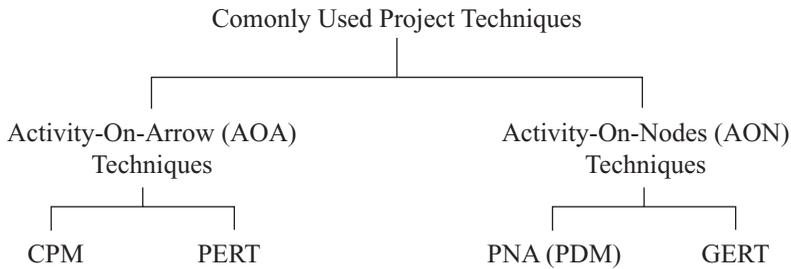
1. CPM Network Analysis Fundamentals
2. CPM Network Development of Pumping Station Project
3. PERT Network Modelling and Time Scheduling Methodology
4. PERT vs. CPM

The methodology for developing time-cost function, which is used for determining economical completion, is covered in **Appendix D**. Precedence network analysis is described in **Chapter 5** and Probabilistic Decision Network Analysis is covered in **Appendix E**. Critical Chain Method is explained in **Chapter 16** and application of Monte Carlo Simulation technique for analysing non-linear duration activities networks is outlined in **Appendix P**. Project networks can be easily developed and analysed using Project Management Software, it is outlined in **Appendix F**.

❑ 4.1   CPM NETWORK ANALYSIS FUNDAMENTALS

A *network* shows the sequence and interdependence of the activities a project in a diagrammatic form by using standard symbols. For example, CPM network of a Pumping Station construction project is drawn in **Exhibit 4.1**.

4.1.1   Network Elements

The two basic elements used in a network are *activity* and *event*. In addition, where necessary, dummy activities are introduced to maintain logic.

Activity.   A project can be broken down into various activities that are necessary for its completion. An activity, as already defined in Chapter 3, is an identifiable, quantifiable, measurable, costable, and discrete lowest level element of work, which must be performed during the course of a project, in order to achieve the project mission. Each of these activities consumes time for their completion. Acquiring land, fixing steel, collecting materials, building a wall, constructing a roof, and curing the concrete are examples of common activities that are involved in a building contruction project.

Exhibit 4.1

Pumping Station Project Time Analysed CPM Network
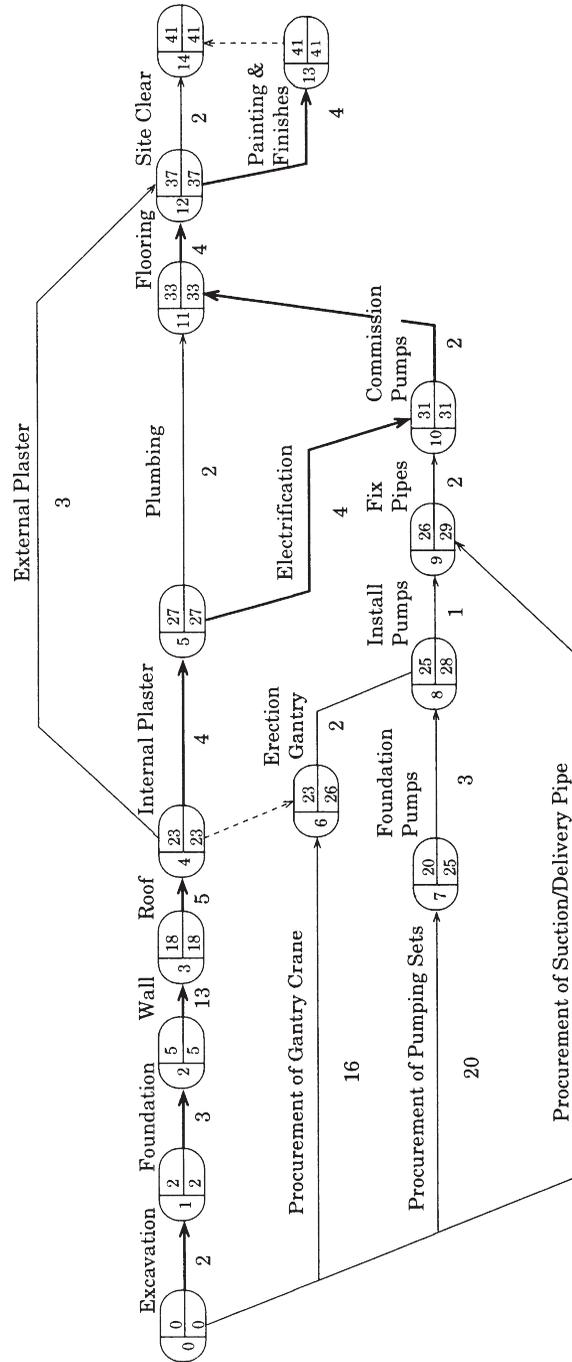
The activities are represented by arrows in the forward direction. The tail of the arrow depicts the commencement of an activity the arrow head represents its termination. The various ways by which the arrow of an activity 'A' can be drawn are shown in **Figure 4.2**:

Figure 4.2

Arrow of an Activity 'A' Drawn in Different Ways
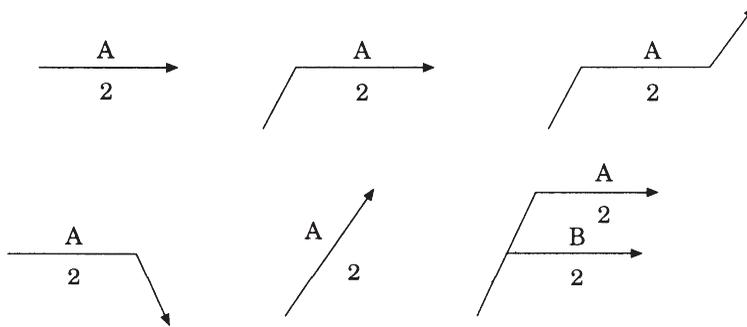
Notes:

1. The description of an activity is written above the arrow and its duration in the middle. An activity excavation needing two units of time for its completion, shown as:

$$\xrightarrow{\text{Excavation}}$$
$$2$$
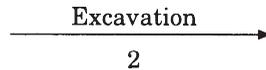
2. The length of the arrow is not drawn to scale. As far as possible, the length of arrow should be so long so that the description of the activity, could be written over it.
3. Arrows are neither curved nor they are drawn in the reverse direction.

Event. It the state that marks the completion of a preceding activity and the beginning of the succeeding one. It has no duration, represents only a single point time. Symbolically, an event is by a circle or an ellipse, as follows:
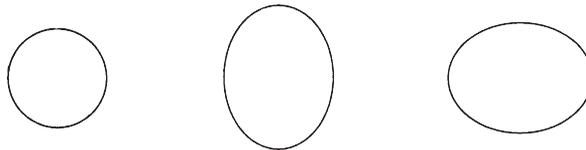
The events are labelled numerically that helps to identify them and describe the connecting activities. The procedure for labelling events is covered in the subsequent paragraphs. An activity (i-j) would be shown as:

Notes:

1. The first event of a project is called as the *start event* and the last *end event*.
2. An event at Which an activity starts is termed as the *preceding event*. The event it terminates is called the *succeeding event*.

3. An event of significance, such as 'electrification complete', 'buildings ready for occupation' etc., is called a *key event*. The occurrence of a key event is termed as the *milestone*.

4. A key event common to two or more sub-networks is called as the *interface event*.

Dummy activity. It is a superimposed activity, which does not represent any specific operation or process. It has zero duration and consumes no resources. Its purpose is two-fold:

a. To provide a logical link in order to maintain the correct relationship of activities.
b. To simplify the description of concurrent activities in terms of event numbers.

The dummy activity is drawn like any other activity, but with dotted lines, as shown below:

Example. Consider a simple task consisting of six activities A, B, C, D, E and F. The du-rations of these activities are 2, 3, 2, 1, 3 and 2 days, respectively. The network is shown in **Figure 4.3**.

Figure 4.3

Network of Activities and their Respective Duration
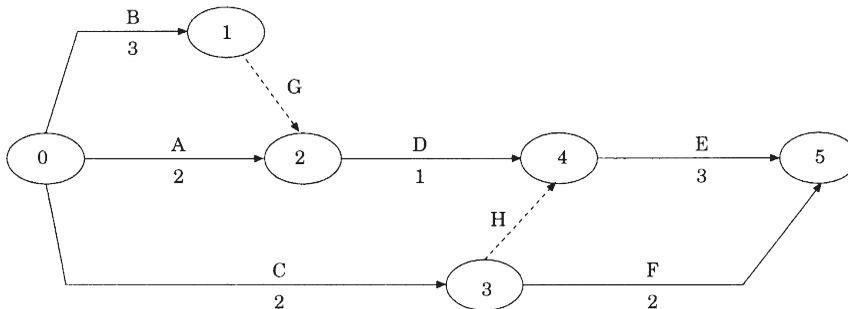
This shows that activities A, B and C start at the same time; D follows the completion of A and B; E starts after C and D are completed; and F follows C. The project is over when E and F are completed.

The points to be noted are:

a. The activities A and B are concurrent (see **Figures 4.4** and **4.5**). To enable their description by event numbers, the dummy activity 'G' has been used.
b. To depict relationship among C, D, E and F; the dummy activity 'H' is introduced (see **Figure 4.6**).

Figure 4.4

Correct Representation of Concurrent Activities
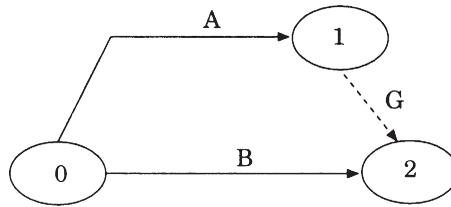
Figure 4.5

Incorrect Representation of Concurrent Activities
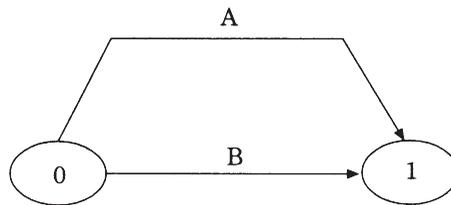
Figure 4.6

Part of Network Showing that F Follows C, and E Starts after Completion of C and D. The Dummy Activity H Provides the Logical Link
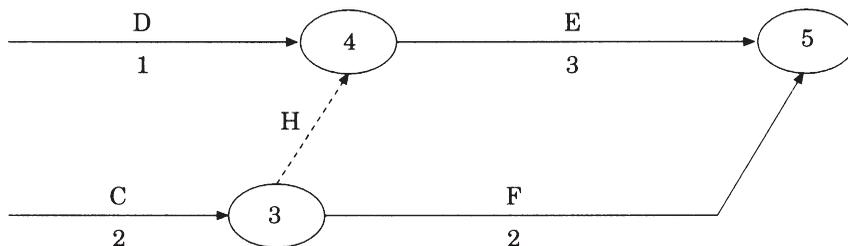
4.1.2   Network Modelling

The development of a network can be by first tabulating the network logic and then drawing the arrow diagram step-by-step. This is illustrated below with a simple example. Consider a work package consisting of nine activities: A, B, C, D, E, F, G, H and J. Their durations are 4, 3, 5, 2, 1, 3, 3 and 2 units, respectively. The logic of activities is tabulated in **Table 4.1**. It is determined by questioning each activity as under:

Table 4.1

Logic Table of Activities

Activity	Preceding	Succeeding	Remarks
A	Nil	B, H	Start activity
B	A	G, J	
C	Nil	H	Start activity
D	Nil	E, G	Start activity
E	D	F	
F	E	Nil	Last Activity
G	B, D	Nil	Last Activity
H	A, C	J	
J	B, H	Nil	Last Activity

1. Which activity/ies precede this activity?
2. Which activity/ies succeed or follow this activity?
3. Are there any logic constraints imposed on this activity?
4. Is it the final activity?

The step-by-step development of the logic arrow diagram can proceed as follows:

- A, C and D can start concurrently in the beginning of the project. Therefore their logic can be represented as:
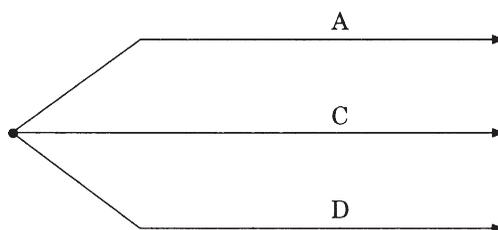
- B follows the completion of A. It can be represented as:
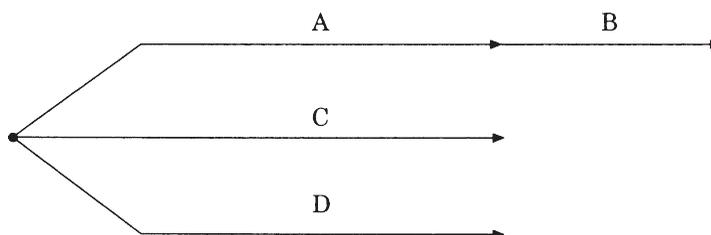
- E starts after the completion of D and is succeeded103' by F. It can be represented as:
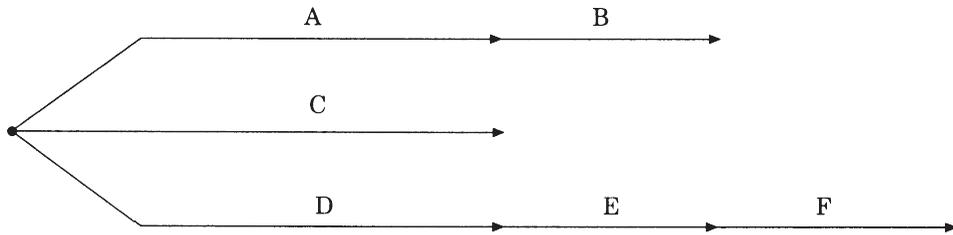
- G starts after the B and D are complete. It can be represented as:
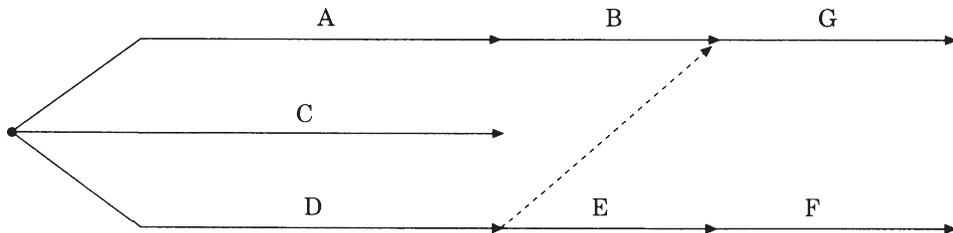
- H follows the completion of A and C. It can be represented as:
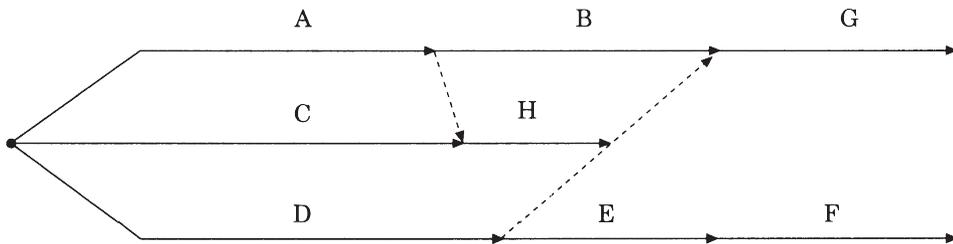
- J succeeds B and H, can be represented as:
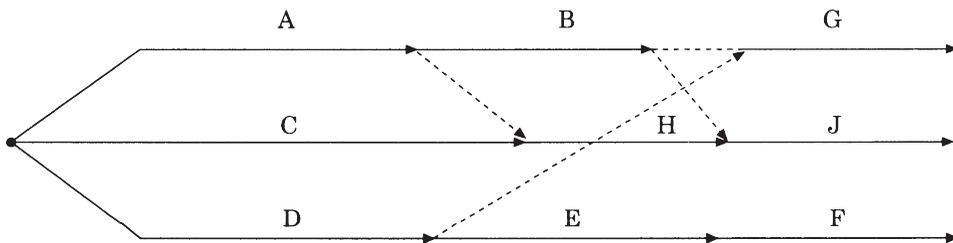
In order to maintain logic and provide the logical link, two dummy activities are introduced. The logic involved, shows that 'G' follows B and D and 'J' starts after the completion of B and H.

- The task is over when F, G and J are completed (**Figure 4.7**).

- The above logic diagram can be converted into the nine-act ivity network by repositioning activities so as to avoid the crossing of arrows, inserting events to mark the start and completion of activities and writing the duration of each activity. This work package network is shown in **Figure 4.8**.

Figure 4.7

Logic Diagram of Activities
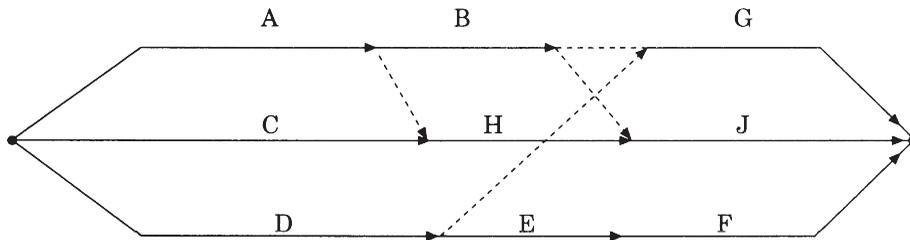
Figure 4.8

Logic Diagram of Nine Activities
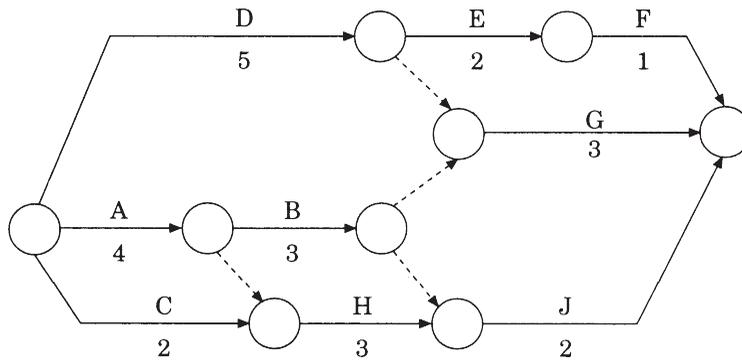
4.1.3 Numbering Events

Purpose.   The numbering of the events serves a three-fold purpose, as follows:

1. It simplifies the identification and description of an activity in terms of event numbers. The activities are coded as '*i-j*', where *i* and *j* are the event numbers the commencement and termination of an activity, respectively.
2. It helps in developing identification code for computer applications.
3. It systematises the computation of critical path. This point is illustrated under the network critical path.

Preferred Rule.   To codify the activities, their numbering can be done in an adhoc manner, provided that unique digits are used for numbering the events. However, the following rules of numbering events help in detecting errors:

1. For each activity, as far as possible, the number of the preceding event (i) should be less than that of the succeeding event (j).
2. If the effort, required in renumbering is (like the insertion of an event after the finalisation of the network would require a renumbering of all the subsequent events), then the next

(higher) number can be given to the new event without altering the other existing numbers. Alternately, events can be labelled in even digit sequence e.g. 0, 2, 4, to cater for insertion of subsequent events at a later time.

Procedure.   Various methods can be used for numbering events, which are in conformity with the rule for numbering. The method given below has an added advantagethat is the numerical sequence indicates the order in which events are considered during time-analysis. This procedure for numbering events is standardised as follows:

1. The start event of the network is numbered as zero. Events can also be numbered as one or by an alpha-numeric identification (ID) code.
2. If there are more than one start events, then these start events can be numbered consecutively in any order, starting with one.
3. Starting with the top chain, the subsequent events in the chain are numbered in the serial order till more than one activity emerges out of an event, or where the tail event of an activity converging into it, is not numbered.
4. Where more than one activity emerges out of an event, the events in the topmost activity or chain are serially numbered first, till an event is reached, where the tail event of the activity converging into it is not numbered.
5. Where the tail event of the converging activity is not labelled, one proceeds with the next activity chain from the top and in that order, following similar procedure, till all events are numbered.

The CPM and PERT networks in this book generally follow the above procedure for numbering events. This procedure is illustrated with a simple example given below.

Numbering Events Example 1:

1. Consider the network given in **Figure 4.9**. The start event is numbered as zero.

Figure 4.9

Network Showing Numbered Events
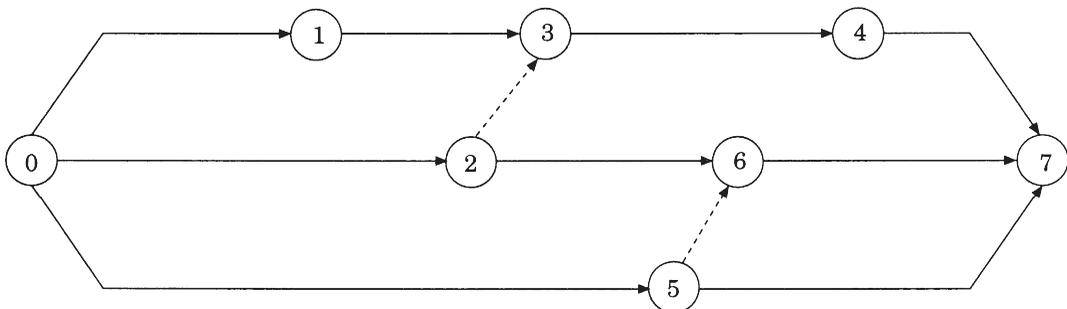
2. Proceeding with the top chain first, the event on top chain is numbered as 1.
3. The event subsequent to event 1 cannot be numbered as the tail event of the dummy activity converging into it is not numbered.
4. Starting with the second chain from top, event 2 is numbered.
5. There are two activities emerging out of event 2; proceeding first with the top chain, events 3 and 4 are numbered.
6. Proceeding similarly, other events can be numbered as shown in the above network.

Numbering Events Example 2:

1. The start event is numbered as zero (see **Figure 4.10**).
2. In the top chain, first event is numbered as 1, and the event subsequent to it is labelled as 2.
3. The event subsequent to event 2 cannot be numbered as the tail events of the activities G and J converging into it are not numbered.
4. Starting with the second chain from top, the events 3, 4, and 5 are numbered serially. Note that the succeeding event of activity G still cannot be numbered as the tail of activity J is not numbered.
5. Proceeding similarly with the bottom chain. The other events are numbered 6,7 and 8, as shown in **Figure 4.10**.

Figure 4.10

Network Showing Procedure for Numbered Events
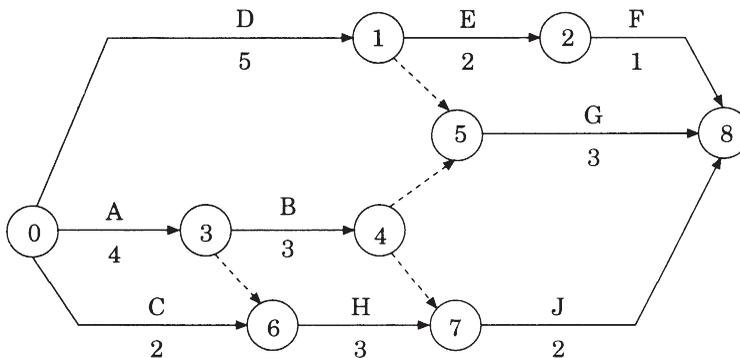
4.1.4   Event Timings and Associated Terms

Each event has two timings associated with it. These are the Earliest Event Time (EET) and the Latest Event Time (LET). The other connected terms are *slack* and *critical* events.

Earliest event time (EET).   It the earliest time at which an event can take place, assuming that all the events prior to it had also occured at their earliest time.

The value of EET is inserted into the circle or ellipse representing the event by suitably dividing them into parts, as shown below:
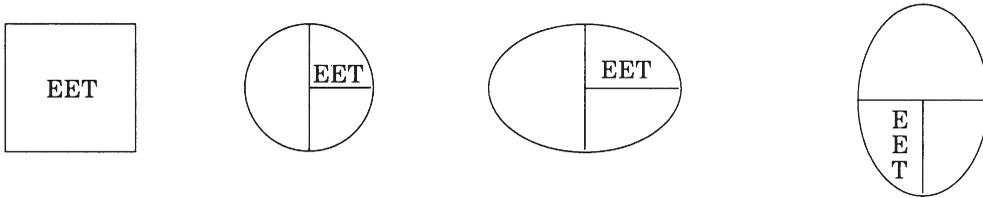
The EET of the first event is set as zero, while the EET of subsequent events is calculated by adding the activity duration to it. If there is more than one activity terminating into an event, the EET of that event is the highest value obtained by adding activity duration to the EETs of the preceding events. This process of determining EET is called *forward pass*.

$$EET_j = EET_i + d; \text{ largest value if more than one path}$$

Take, for example the network given in **Figure 4.11**. The EET of the start event zero (g the completion of activity B, designated as EET_1, is $0 + 3 = 3$. EET_2 has the highest value (3) of the duration along paths 0–1 and 0–2. EET_3 is $0 + 2 = 2$. Similarly, EET_4 and EET_5 are 4 and 7, respectively.

Figure 4.11

Network Illustrating Calculation of Earliest Event Time (EET)
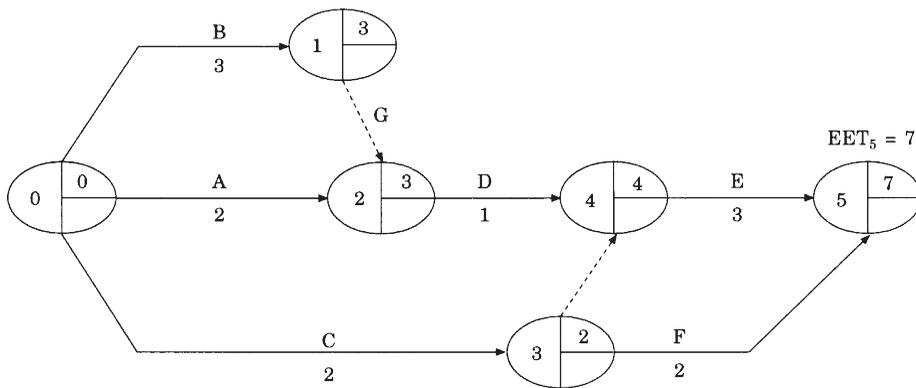
Latest event time (LET).   It is the latest time by which an event can occur, if the project is to be completed within the specified time. The LETs are written as:
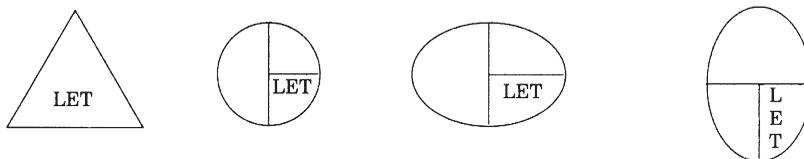
Unless otherwise specified, the LET of the end event is taken equal to its EET. The LETs of the remaining events are calculated by moving in a reverse path and subtracting the activity duration from the LET at the head of the activity.

$$LET_i = LET_j - d; \text{ lowest value if more than one path}$$

If more than one activity diverges from an event, its LET would be the lowest value obtained by subtracting the duration of each activity from the LET of the respective succeeding event. This process of determining LET is *back pass* or *backward pass*.

The LETs of the sample network discussed earlier are shown in **Figure 4.12** and **Figure 4.13**. Note that the LET of event 3 (LET_3) is the lowest value (4) of paths connecting events 34–5 and events 3–5.

Figure 4.12

Network Illustrating Calculation of Latest Event Time (LET)
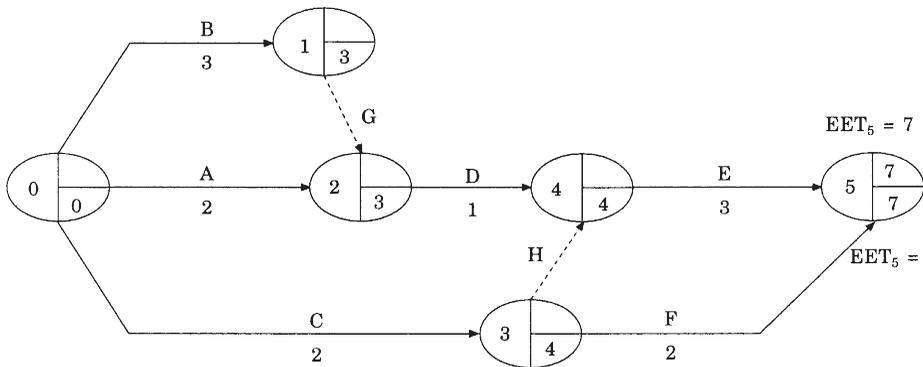
Figure 4.13

Network Showing Critical Events
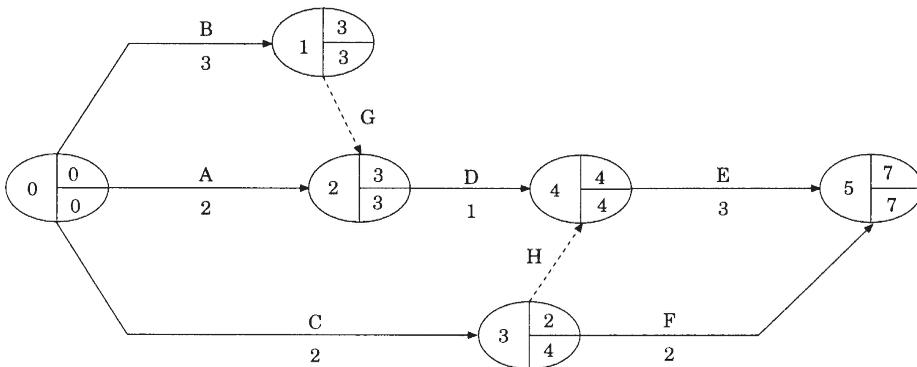
Slack. The difference between the LET and EET of an event is called *slack* or *event slack*. It gives the time within which the event must take place if the project is to be completed on schedule. For example, the slack of the event 3 would be:

$$\text{LET}_3 - \text{EET}_3 = 4 - 2 = 2$$

Critical events. The events having a zero slack are called critical events. They must take place at a stipulated time without fail. There is no flexibility in their schedule. Any change in their occurrence would affect the project completion time. For example, the events 0, 1, 2, 4 and 5 of the network given in **Figure 4.12** have LETs equal to EETs. These are its critical events.

4.1.5 Activity Timings and Connected Terms

Corresponding to the event timings at its beginning and termination, each activity has four timings associated with it. These are the Earliest Start Time (EST), the Latest Start Time (LST), the Earliest Finish Time (EFT) and the Latest Finish Time (LFT). The other connected terms are *float* and *critical activities*.

Earliest start time (EST). This is the earliest time an activity can be started, assuming that all the activities prior to it have taken place as early as possible. The EST of an activity is equal to the EET of the preceding event, that is,

$$\text{EST} = \text{EET}_i$$

Latest start time (LST). This is the latest time by which an activity can start in consistent manner, with the completion of the project in the stipulated time. The LST of an activity is determined by subtracting the activity duration from the LET of the succeeding event, that is,

$$\text{LST} = \text{LET}_j - d$$

For example, the LST of activity 'F' in the network shown in **Figure 4.13**.

$$= \text{LET}_5 - d = 7 - 2 = 5$$

Note: The LST of activity 'F' is not the same as the LET of its preceding event.

Earliest finish time (EFT). It is the earliest time by which an activity can be completed, assuming that all the activities prior to it begin at their ESTs. The Earliest Finish Time (EFT) is calculated by adding the activity duration to EST. For example, the EFT of activity F:

$$\text{EFT} = \text{EET}_3 + d = 2 + 2 = 4$$

Latest finish time (LFT). It is the latest time by which an activity must be completed to ensure the completion of project within the stipulated time, that is,

$$\text{LFT} = \text{LET}_j$$

Float.   The difference between the Latest Start Time (LST) and the Earliest Start Time (EST) of an activity is called *float, total float* or *activity slack*. Float is a measure of the amount by which the start of an activity can be delayed in consistent with the completion of the project on time. Mathematically, the float is represented as:
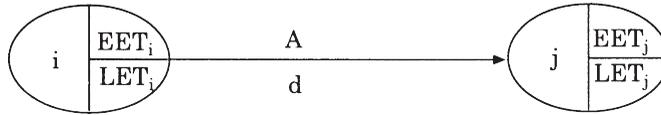
For example, for an activity 'C', the float would be:

$$\text{Float} = \text{LST} - \text{EST}$$
$$= \text{LET}_3 - d - \text{EET}_0$$
$$= 4 - 2 - 0 = 2$$

Similarly the floats can be calculated in **Table 4.2**. **Chapter 6** deals with the various types of floats and their applications.

Table 4.2

Activity and Float Calculation

Activity Code	Activity Description	Float = $\text{LET}_j - d - \text{EET}_i$	Remark
0–1	B	$3 - 3 - 0 = 0$	Critical activity
0–2	A	$3 - 2 - 0 = 1$	
0–3	C	$4 - 2 - 0 = 2$	
1–2	G	$3 - 0 - 3 = 0$	Critical activity
2–4	D	$4 - 1 - 3 = 0$	Critical activity
3–4	H	$4 - 0 - 2 = 2$	
4–5	E	$7 - 3 - 4 = 0$	Critical activity
3–5	F	$7 - 2 - 2 = 3$	

Critical activities.   activities (including dummy) having a zero float are called *critical activities*. For example, in the Network drawn in **Figure 4.13**, the activities B, G, D and E are critical activities as their float is zero.

The activity A connects two critical events, 0 and 2, but it is not a critical activity as its float is 1. All critical activities must join two critical events, but all activities joining two critical events are not necessarily critical themselves. For easy identification, the critical activities are shown by any or a combination of the following:

(i)   Two small vertical lines in the middle of an arrow;

(ii) A thick line; and

(iii) A combination of (i) and (ii).
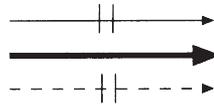
In the network shown in **Figure 4.14**, B, G, D and E are critical activities and the sum of duration along the critical path is 7 time units (i.e. $3 + 0 + 1 + 3 = 7$).

Figure 4.14

Network Showing Critical Activities
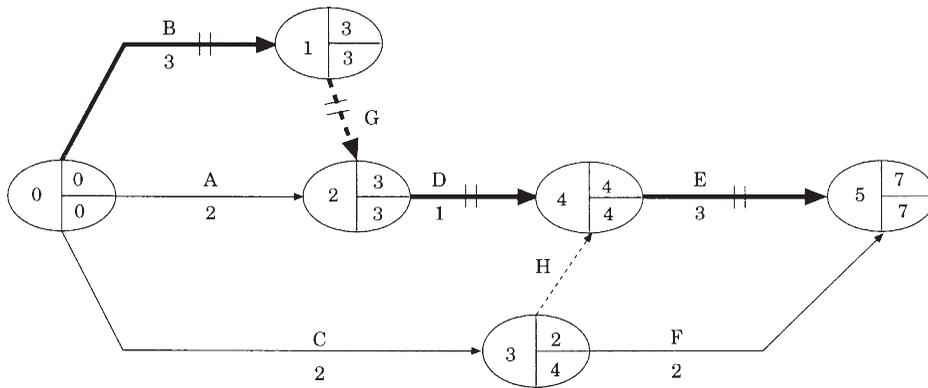
The term *zero float* implies that the activity must commence and terminate at the specified time. Any delay in the start and completion time of a critical activity will increase the duration of the project Network critical activities are shown in **Figure 4.14**.

4.1.6   Network Critical Path

The path of critical activities (including dummy activities), which links the start and end events is called *critical path*. In other words, it is the path of activities having zero float and events having zero slack. The sum of the duration of the critical activities along a critical path gives the duration of the project. These are illustrated with the network given in **Figure 4.10**.

Determining earliest event times (EET).   The EET of the start event is set as zero time. Then, moving in the forward direction, the succeeding events are selected one by one in the ascending order of their event number code. The EETs are processed systematically. If there is more than one path converging into an event, its EET the value obtained along the longest path. Further, during analysis, the earliest event timings can be worked out and written directly on the network, as shown in **Figure 4.15**.

Figure 4.15

Network Showing Earliest Event Times (EET)
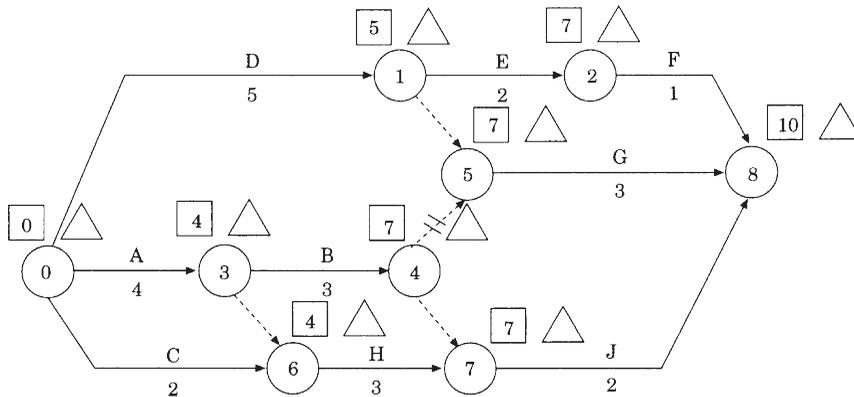
Note: The minimum project duration is equal to the EET of the end event.

Calculating latest event times (LET).   If the project is to be completed on schedule, the LET of the end event must be taken equal to the laid down completion time. Generally, in the initial stages the project completion time constraints are not considered and LET of the end event is equal to the minimum project duration indicated by the EET of the end event. The LET of the remaining events are calculated by reversing the method followed for determination of the EET. In practice, the LETs are directly worked out on the network, as shown in **Figure 4.16**.

Figure 4.16

Network Depicting Latest Event Times (LET)
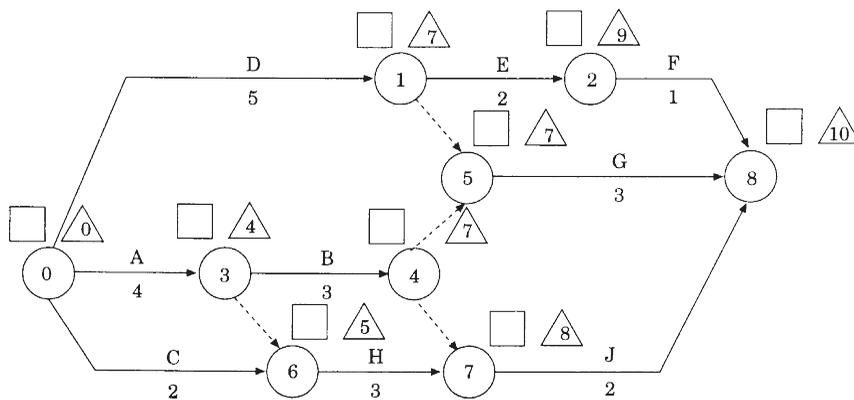
Isolating critical events.   The slack of an event is equal to the difference between its LET and EET. The events having zero slack are termed *critical events*. After working out, the LETs and

EETs of all the events on the network, the critical events having zero slack can be spotted. In the network shown in **Figure 4.17**, the critical events are 0, 3, 4, 5 and 8.

Figure 4.17

Network Showing Critical Path
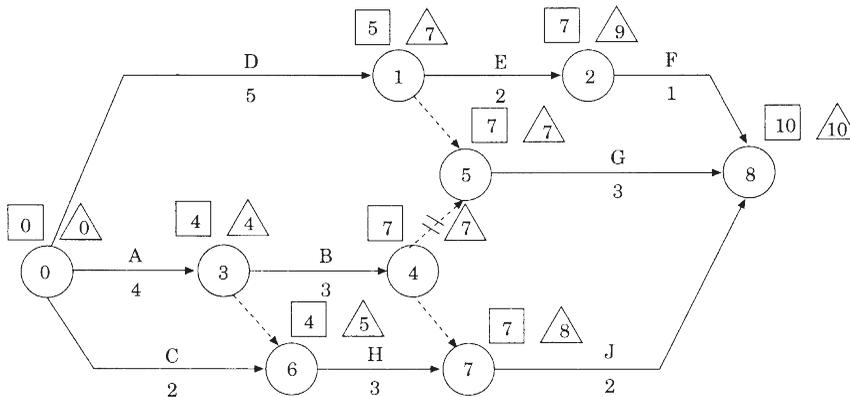
Identifying critical activities. The critical activities are always joined by critical events, but an activity joining two critical events may not necessarily be a critical activity. It is therefore essential that floats of all activities (including dummies) critical events should be worked out and activities having zero floats should be identified.

$$\text{Float} = \text{LET}_j - d - \text{EET}_i$$

After identification, the critical activities should be marked on the network using the conventional symbol (as shown in **Figure 4.17**).

4.1.7 Significance of Critical Path

1. It is the longest path in the network. However, it is possible for a network to have more than one critical path. The sum of the durations of critical activities along the critical path determines the duration of the project.
2. It is the most sensitive path, which means any change in duration of a critical activity along the critical path is bound to affect the duration of the entire project.
3. By isolating critical path, the project management can exercise 'management by excep-tion', thereby focusing its attention on the critical activities.

❑ 4.2 CPM NETWORK DEVELOPMENT OF PUMPING STATION PROJECT

4.2.1 CPM Network Modeling and Time Analysis

An experienced planner can develop the CPM sub-network of a sub-project or a task, working straight from its Work Breakdown Structure or Task Matrix. However, for a beginner, a step-wise approach

can systematise modelling and time analysis of the network. This step-by-step procedure involves, defining the scope of network, listing activities, developing logic diagram, structuring network, incorporating activity durations, numbering events, and computing the critical path (see **Table 4.3**).

Table 4.3

CPM Network Modelling and Time Analysis Procedure

Defining scope of network
Determining activities
Establishing logic of activities
Developing network logic diagram
Structuring model
Incorporating activity duration
Numbering events/activities
Time analysing network
(Time compress critical path, if required)

The network analysis procedure is illustrated with the help of a simple pumping station sub-project, are discussed in **Chapter 3**. The work scope of this sub-project includes construction of a pumping-station building, procurement and installation of the pumping sets, erection of gantry crane, and commissioning of the installation. The contract for the sub-project has been finalised and the network is to be drawn for controlling the execution of the contracted works.

It is emphasised that the network should be drawn preferably after finalising the construction methodology. Further, logic should not get bogged down with focus on resource availability as these are consider during scheduling (**Chapter 6**). Accordingly, one should focus on the procedure of modelling and analysis of network illustrated in the following paragraphs, rather than debating the method .

4.2.2   Defining the Scope of Network

From its conception to its evolution and completion, a project has innumerable activities associated with it, but it is not necessary to include all of them in the network.

For example, a network drawn for systematic execution of contracted work need not to be included the pre-contract planning and designing activities. The first step in network modeling, is to define the scope of the network by fixing start and end events, stating suitable assumptions, and lying constraints.

1. ***Start and end events***. These define the extent of the network. The contract period of work commences from the time of handing over site to the contractor, which can be treated as the start event. The clearance of site after completion of work is generally the last activity of a contract and completion of the activity becomes the end event. For the major multi-project networks, there may be more than one start and end event.

2. ***Assumptions***. These are the statements that are assumed to be true and from which the conclusions can be drawn. These aim at reducing the network size by omitting unnecessary details. Suitable assumptions can also be made about the 'unpredictable, the network.

3. ***Constraints***. The restrictions and limitations, like those arising from the method of execution, priorities of the work, and availability of resources. Such cases impose constraints on sequencing of activities. The nature of constraints and their implications on schedule development and controlling time are covered in respective chapters.

4. Consider the example of pumping station sub-project. The scope of the network is defined as reflected in **Table 4.4**.

Table 4.4

Scope of Network: Pumping Station Project

1.   *Extent of network*
(i) *Start event*   Handing over of the site to the contractor.
(ii) *End event*   Clearance of site, after completion of the works.
2.   *Main assumptions.*   The contractor has ascertained the availability and delivery period of the specified pumps, gantry crane and fittings prior to tendering. But, he shall be placing the supply order for these immediately after the award of the contract.
3.   *Constraints*
(i) The work on concreting of foundation for pumping sets must not commence before the procurement of the pumping sets. This is to ensure that foundation bolts and other inserts are correctly embedded.
(ii) The gantry crane must be erected prior to the installation of pumping sets.
(iii) The flooring work can commence only after commissioning of the pumping sets.

4.2.3   Determining Activities

The various stages in the execution of a project can easily be visualised by breaking down the work into major tasks or work packages. Each one of these can further be split into sub-tasks, these sub-tasks can be further sub-divided; this process continues till the desired level of activities is reached. The technique of breaking down the project into its component activities has already been described in Chapter 3. The activities derived for the pumping station sub-project are given in **Table 4.5**.

4.2.4   Establishing Logic of Activities

The logic of activities within the work package can easily be established by asking the following questions relating to each activity:

1. Which activity/ies precede this activity?
2. Which activity/ies succeed or follow the completion of this activity?
3. Are there any constraints imposed on starting of this activity?

Table 4.5

Activities of Pumping Station Project

Work Package No. 1	Building Structure
B	- Foundation
C	- Walling
D	- Roofing
Work Package No. 2	Procurement of Equipment
E	- Procurement of crane gantry
F	- Procurement of pumping sets
G	- Procurement of suction/delivery pipes
Work Package No. 3	Installation and Commissioning of Pumping Sets
H	- Erection of gantry
I	- Foundation of pumps
J	- Installation of pumping set
K	- Fixing of suction and delivery pipes
L	- Commissioning of pumping sets
Work Package No. 4	Finishes and Essential Services
M	- Internal plaster
N	- External plaster
O	- Plumbing and sanitary fittings
P	- Electrification
Q	- Laying floor
R	- Painting and Finishes
S	- Site clearance

4. Is it the final activity? If so, what are the activity/ies that precede this activity?

The above questioning technique enables determination of the logic preceding and succeeding activities of each activity. The activity logic, thus obtained, can be complied in the form of an activity-

dependence table. To quote an example, activity-dependence table of Pumping Station Project is given in **Table 4.6**.

Table 4.6

Pumping Station Project Activity Dependence Table

Activity Code	Activity Description	Activity Duration	Preceding Activity(s)	Succeeding Activity(s)
WP No. 1	**Building Structure**			
A	- Excavation	2	-	B
B	- Foundation	3	A	C
C	- Walling	13	B	D
D	- Roofing	5	C	H, M, N
WP No. 2	**Procurement of Equipment**			
E	-Procurement of crane gantry	16	-	H
F	-Procurement of pumping sets	20	-	I
G	-Procurement of suction/delivery pipes	10	-	K
WP No. 3	**Installation and Commissioning of Pumping Sets**			
H	- Erection of gantry	2	D, E	J
I	- Foundation of pumps	3	F	J
J	- Installation of pumping set	1	H, I	K
K	- Fixing of suction and delivery pipes	2	G, J	L
L	- Commissioning of pumping sets	2	P, K	Q
WP No. 4	**Finishes and Essential Services**			
M	- Internal plaster	4	D	P, O
N	- External plaster	3	D	R, S
O	-Plumbing and sanitary fittings	2	M	Q
P	- Electrification	4	M	L
Q	- Laying floor	4	L, O	R, S
R	- Painting and Finishes	4	N, Q	End
S	- Site clearance	2	Q, N	End

At times in the initial stages, the preceding and succeeding activities connecting the work packages are difficult to determine, but they become apparent during integration. Further, it is not necessary to determine, both, preceding and succeeding activities; logic gets established with preceding activities, however, succeeding activities logic can help in verification of the sequencing of activities.

4.2.5   Developing Network Logic Diagram

The main purpose of the logic diagram is to facilitate the drawing of network. The preparation of logic diagram can be divided into three stages: (i) developing logic diagram for each work package, (ii) integrating work packages, and (iii) transforming integrated work package logic diagrams into a project logic diagram. In practice, work packages are considered in the sequence they occur. Further, the drawing of workpackage logic diagrams and the process of integration can be carried out simultaneously.

Developing workpackage logic diagram.   The activity-dependence table, provides the necessary data for developing the workpackage logic arrow diagram.

Logic diagrams can be developed for each workpackage. These diagrams based on the logic, given in the activity-dependence table (see **Table 4.6**) for each work package of the pumping station sub-project are shown in **Figure 4.18**.

Integration of workpackage logic diagrams.   The term *integration* implies the connecting of logic diagrams of the work packages into a single-project logic diagram. Prior to the commencement of integration, it is e ssential that, as far as possible, the paper on which the project logic diagram is to be drawn is divided into various strata. The term *stratification* means division of the diagram in such a way that activities pertaining to the same depart-ment, contract, site, location or method of construction, can be suitably grouped by drawing horizontal and/or vertical imaginary lines. Generally, the integration link can be visualised from the Work Breakdown Structure.

The process of integration logic diagram is commenced from the beginning of the project, work packages falling in the same strata are connected in their occurring sequence. While integrating, the sequence of activities terminating into and emerging out, along with the connecting key events must be verified by questioning each about its preceding and succeeding activity.

Broadly, the integration of the work packages of the pumping station sub-project can be divided into two strata, namely, civil works and mechanical works, see **Figure 4.19**.

While integrating the workpackage diagrams, the logic of all the activities should be re-examined to find their interdependence. This interdependence can initially be correlated with dummy activities. In some cases, the activities may have to be re-drawn to conform to a given logic.

The sub-project logic diagram, derived after integrating the workpackage logic diagrams of civil and mechanical works of the pumping station sub-project, is shown in **Figure 4.19**. The main points to considered are:

a. The start event is common to both civil and mechanical works logic diagram.
b. The erection of gantry is to start after completion of roofing. A dummy activity has been interposed to maintain this logic.
c. The commissioning of pumping set can commence after the electric lines have been laid. This is shown by a dummy activity.

Figure 4.18

1. Building structure sub network

Note: Start event is circled and numbered zero; last circle is labeled 1.

2. Equipment procurement sub network
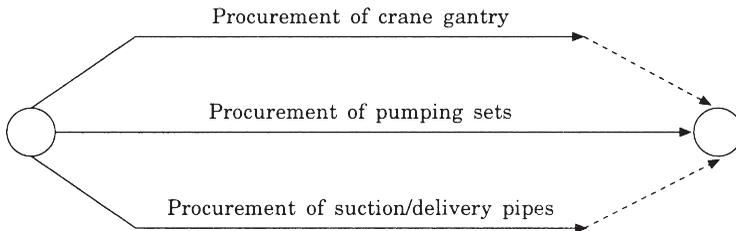
3. Building finishes sub network
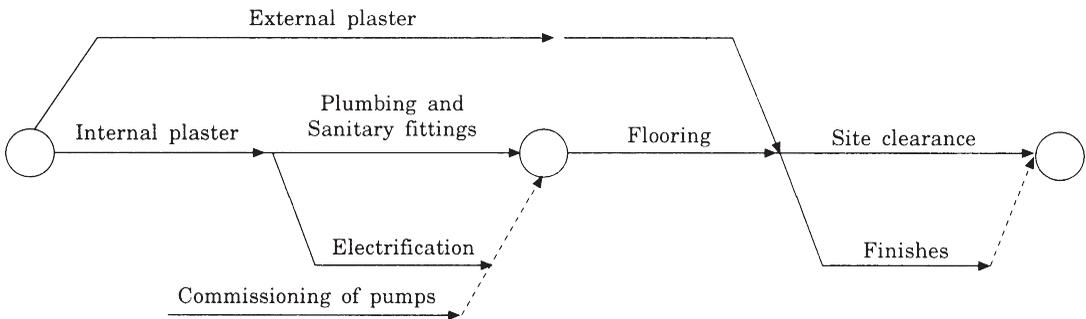
Note: All the above activities can be commenced from the start event and they can run concurrently.

4. Equipment installation and commissioning sub network
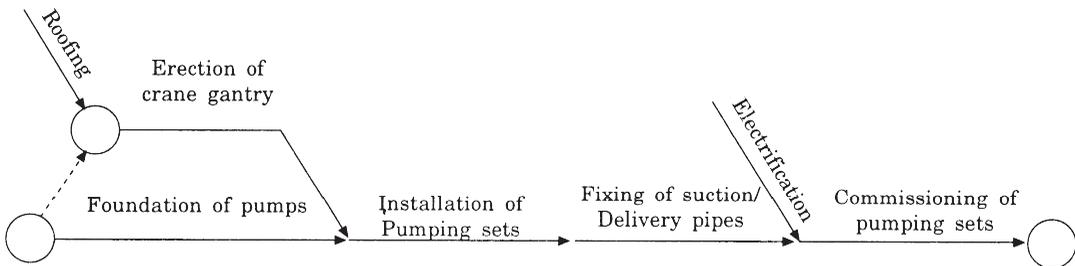
Note: The activities linking other work packages.

Figure 4.19

Logic Diagram of Pumping Station Project
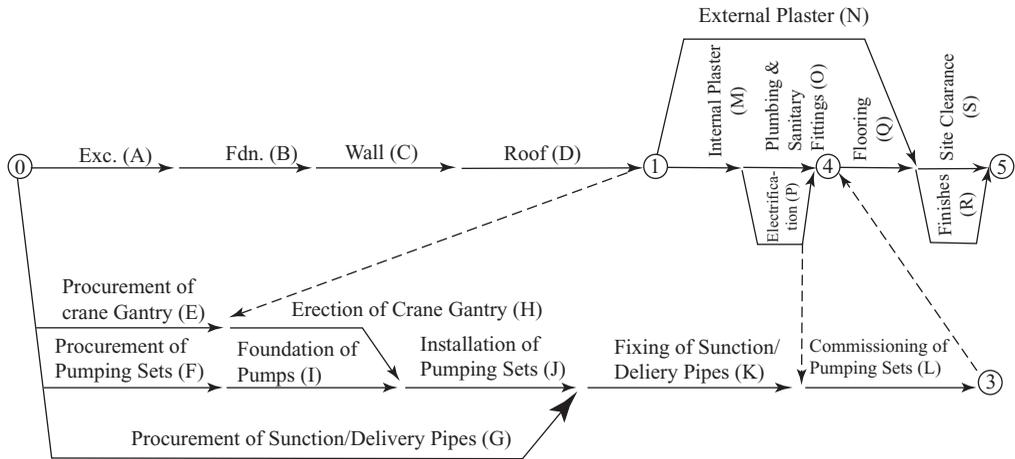
d.   It is desirable to complete the plumbing and sanitary works and commission the pumping set prior to the laying of floor, so as to avoid breaking floor surface, in case of defects.

A dummy, connecting circles 3 and 4, has been used to show this logic.

4.2.6   Preparation of Logic Diagram and Draft Network

The main purpose of the flow diagram is to facilitate a systematic drawing of the draft. The guidelines for converting the logic diagrams into draft network are:

a.   The dummies should be reduced to minimum.
b.   The crossing of arrows should be avoided by a suitable re-positioning of the activities.
c.   The new activities should be incorporated, if visualised during the preparation of logic diagrams.
d.   Logic of all the activities should be verified for its correctness.

Figure 4.20 also shows the draft network diagram of the pumping station sub-project.

Figure 4.20
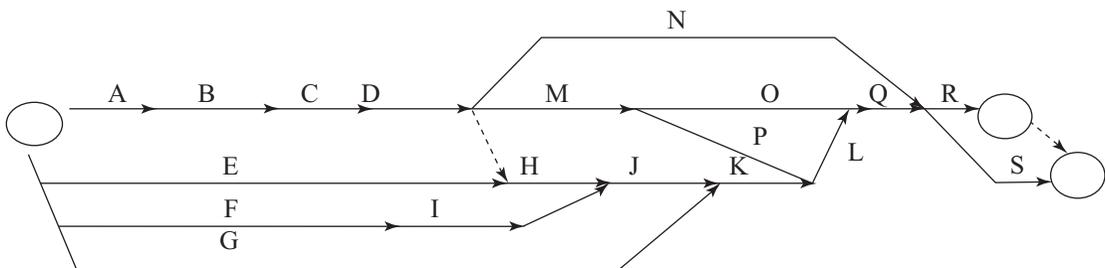
4.2.7   Structuring Model Using Network Drawing Rules

The project networks are constantly read, referred and reviewed. Therefore, it is essential that they should be suitably titled and numbered, neatly drawn by readable lettering printed horizontally, and divided into strata for easy reference.

The various conventions and rules for drawing CPM network are given below. The master network of pumping station project is shown in **Exhibit 4.1**.

1. All arrows must run from left to right. Turning arrows in the reverse direction is not correct dummies should be reduced to minimum.
2. The new activities should be incorporated, if visualised, during the preparation of logic diagrams. Logic of all the activities should be verified for its correctness.
3. The arrows should have sufficient horizontal length, so that a description could be written over it.
4. The crossing of arrows should be avoided by suitably re-positioning them.
5. Arrows running close to each other should be avoided. The intervening space should be sufficient to permit writing of activity description.
6. The concurrent activities (commencing or terminating into common events), where necessary arrows should be separated by inserting additional events followed by dummy activities.
7. The activities emerging from an event should take-off from a line rather than a point. Similarly, activities terminating into an event should finish into a common line.
8. Wherever possible, the network should be drawn in such a way that activities belonging to the same strata can be by drawing vertical and/or horizontal lines.
9. Use of large sheets should be avoided. If required, a large network can be split into two or more sheets having common interface events. For easy recognition, the interface events can be represented by double circle or ellipse.
10. The network should be re-drawn, if necessary, to give it neat appearance.
11. Prints of important networks should be taken and circulated to all concerned authorities or departments for and feedback. Amendments should be carried out, if necessary.

4.2.8   Incorporating Activity Duration

The duration of activities are estimated, while breaking down the project into activities. Further, some new activities may also get added during the preparation of network. Therefore, after drawing the network, the duration of all the activities should be re-checked and necessary corrections made.

4.2.9   Numbering the Events

This is the last operation in the modelling of the network. The procedure for numbering the events is explained in Section 4.1.3. It is as follows:

- The start event of the network is numbered as zero;

- Starting with the top of the chain, the subsequent Events 1 to 4 in the chain are numbered serially till more than one activity emerges out of Event 4;
- Next consider activity, 'External Plaster' in the top most chain emerges out of Event 4. Its terminating event cannot be numbered the tail event of the activity converging into it is not numbered;
- Select the next activity chain from the top and label it as Event No. 5; and
- Follow similar procedure till all the events are numbered as shown in **Exhibit 4.1**.

4.2.10   Time Analysing Network

The critical path computation procedure involves:

- Determining the Earliest Event Time (EET) by forward pass analysis;
- Calculating the Latest Event Time (LET) by backward pass analysis;
- Evaluating activity floats;
- Identifying critical activities; and
- Highlighting critical paths.

This time analysis can be carried out directly on the network, as shown on the pumping station subproject in **Exhibit 4.1**. The activity timings are computed in **Table 4.7**.

4.2.11   Time Compression of the Critical Path

Normally, a project should be planned for the completion period determined from the network (plus some reserve extra time). Increasing the duration of the project beyond its optimum completion time is out of question, since, it would only add to the overhead costs of the project. But if the analysed completion time is greater than the desired time objective, the time compression of the project critical path can be explored by modifying the network without any increase in the cost of activities.

Time compression of the critical path involves splitting (where feasible) the critical activities into smaller ones, either by using different methods of execution without any appreciable change in resources or by switching over to a lower level of activity details. Some of these smaller activities may form a chain of activities, while, others may be in parallel manner. Generally, it is the parallel component of the critical activities that enables a compression of the project completion time as given in **Figure 4.21**.

If time compression does not meet the project completion time target, then the network will have to be subjected to time crashing. The methodology for Time-Cost Trade-Off technique, which forms the basis for developing time-cost function and Time Crashing, is covered in **Appendix D**.

❑ 4.3   PERT NETWORK MODELLING AND TIME ANALYSIS METHODOLOGY

4.3.1   Modelling PERT Network

The Programme Evaluation and Review Technique (PERT) is employed for planning and controlling the projects involving uncertainties.

Table 4.7

Pumping Station Project

EST = EETi;   EFT= EETi +d
LST = LETj–d; and, LFT = LETj
Float = LST – EST = LETj – d–EETi; *Critical Activities having zero float

Code	Activities Description	Activities Data				
		Dur.	EST	EFT	LST	LFT
	*Start Event	0	0	0	0	0
0–1*	Excavation	2	0	2	0	2
1–2*	Foundation	3	2	5	2	5
2–3*	Walling	13	5	18	5	18
3–4*	Roofing	5	18	23	18	23
4–5*	Internal plaster	4	23	27	23	27
4–6	Dummy	0	23	23	23	26
0–6	Procurement of crane gantry	16	0	16	10	26
0–7	Procurement of pumping sets	20	0	20	5	25
0–9	Procurement of suction/delivery pipes	10	0	10	19	29
6–8	Erection of gantry	2	23	25	26	28
7–8	Foundation of pumps	3	20	23	25	28
8–9	Installation of pumping set	1	25	26	28	29
9–10	Fixing of suction and delivery pipes	2	26	28	29	31
10–11	Commissioning of pumping sets	2	31	33	31	33
4–12	External plaster	3	23	26	34	37
5–11	Plumbing and sanitary fittings	2	27	29	31	33
5–10*	Electrification	4	27	31	27	31
11–12*	Laying floor	4	33	37	27	37
12–13*	Painting and Finishes	4	37	41	37	41
13–14*	Dummy	0	41	41	41	41
12–14	Site clearance	2	37	39	39	41

Note: Dummy activities must also be time analysed to determined floats. *Critical Activities having zero float.

Figure 4.21

**Part of the Network Showing the Significance of Resolving an
Activity 5-10 into Two Parallel Activities**
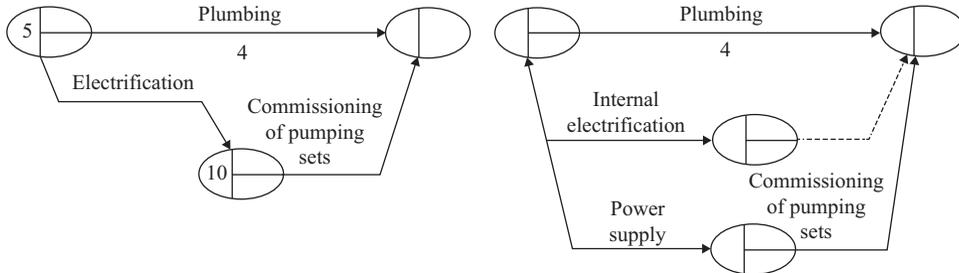
PERT is an event-oriented technique based on a network of events the activities are derived by connecting the events. It lays stress on measuring the uncertainty in activity times by using the three-times duration estimation method. For computation of critical path, the PERT three-times probabilistic network is converted into a single-time deterministic CPM Model. PERT studies the implications of uncertainties on scheduling project time and slack of events by employing statistical tools.

Two special features of PERT distinguish it from the other network analysis techniques. These features are emphasis upon events rather than activities and the use of three-times estimate for activity duration. **Exhibit 4.2** illustrates the PERT network of pumping station subproject.

The PERT networkmaking approach is to identify the milestones necessary for successful completion of the project. These milestones are then depicted in the form of a key-events network showing their sequence and interdependence. After this, the events visualised between the milestones are added and their interrelationship gets established. These event nodes represent points in time, which are generally terminal in nature. The activities are derived by interconnecting the events. The event diagram thus obtained is converted into event oriented PERT network using the network drawing rules.

The steps involved in this technique are:

- Identification of key events or milestones which must occur during the project execution;
- Determination of the sequence and interdependence of the key events;
- Incorporation of events (or activities) between the milestones, conforming to their sequence of occurrence; and
- Connection of events, maintaining their interdependence.

This gives the project flow diagram from which the network can be drawn directly using the network drawing rules.

It may be noted that while determining the three-time estimate, the optimistic and pessimistic times should be assessed first. These two extremes bracket the most likely time, thus helping the

Exhibit 4.2

PERT Network of Pumping Station Project
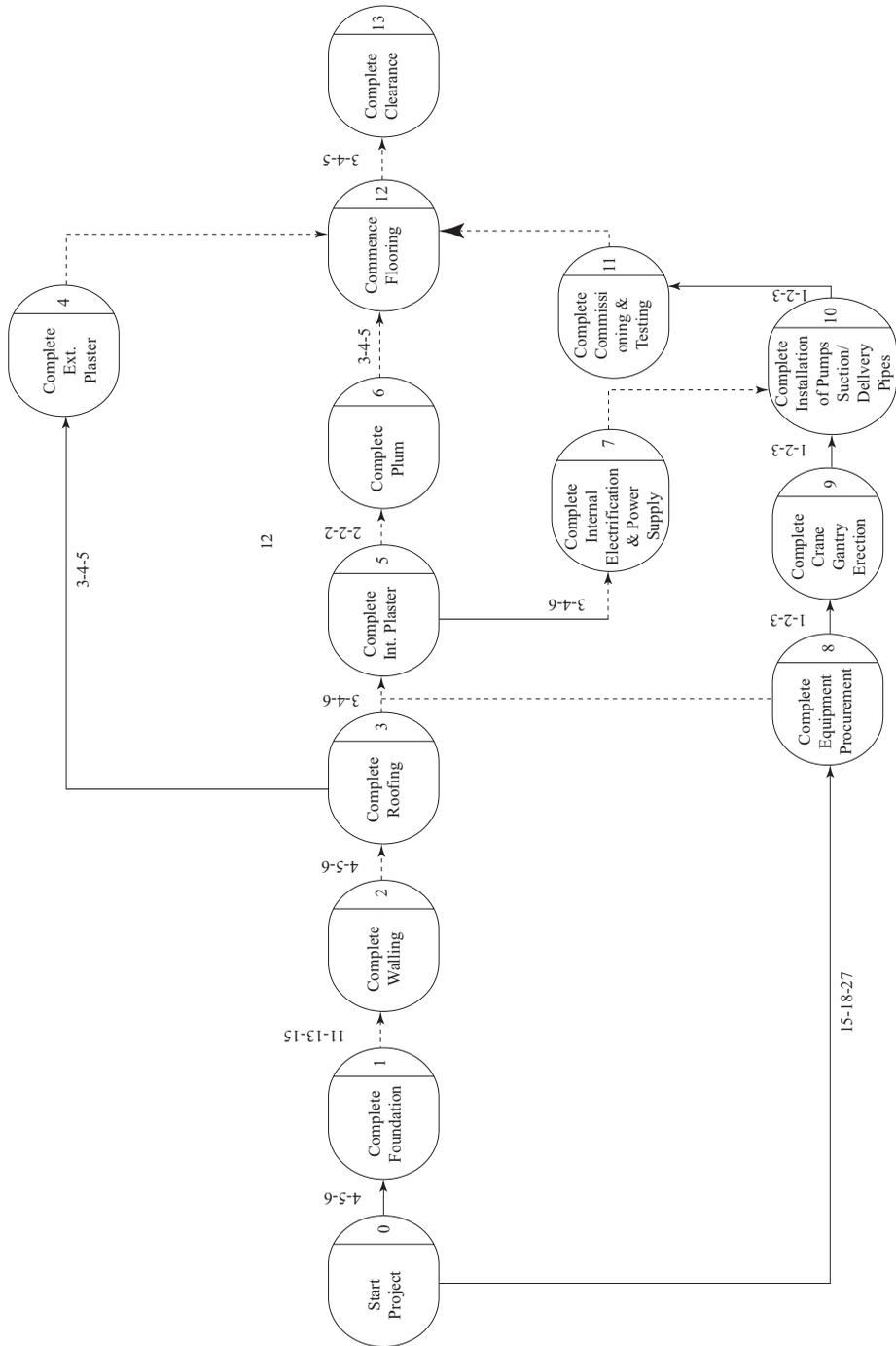
planners to concentrate within this range. There is also a tendency of planners to either use the same figure for all the three-times (say, 9, 9 and 9) or arrive at the most likely time first and then

arrive at the optimistic and pessimistic time by subtracting and adding an equal amount (say, 6, 9 and 12). These trends should be avoided because such estimates are likely to be conservative.

4.3.2 Computing Critical Path

The first step in computing the critical path in PERT network is to reduce the three-time activity durations estimate into single expected time estimate. The rest of the procedure for computing critical path of PERT network is exactly the same as of the CPM network. The steps involved in computing critical path are as follows:

1. Estimate the expected activity duration. It is given by the following formula:

$$T_e = \frac{T_o + 4T_m + T_p}{6}$$

where,

T_e = Expected activity duration

T_o = Optimistic time, assuming that everything goes extremely well with no delays

T_p = Pessimistic time, assuming that everything occurs at its worst, with the exception of delays due to acts which cannot be foreseen.

T_m = Most likely time, assuming the normal prevailing conditions.

As an example, consider PERT network outlined in **Figure 4.22**.

Figure 4.22
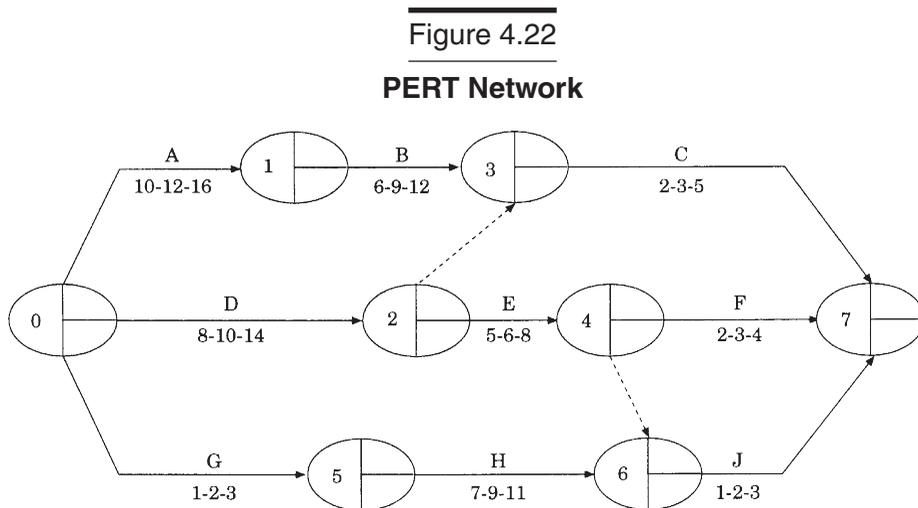
PERT Network

Using the three-time activity duration estimation formula, the expected activity timings can be calculated as in **Table 4.8**.

2. Convert PERT network into deterministic model. It is done by changing the three time activity durations in PERT to the one-time expected estimates as shown in **Figure 4.23**.

Table 4.8

Expected Activity Timings

S. No.	Activity	T_o	T_m	T_p	T_e
1	A	10	12	16	12.3
2	B	6	9	12	9.0
3	C	2	3	5	3.2
4	D	8	10	14	10.3
5	E	5	6	8	6.2
6	F	2	3	4	3.0
7	G	1	2	3	2.0
8	H	7	9	11	9.0
9	J	1	2	3	2.0

Figure 4.23

Converting PERT Network into Deterministic Model
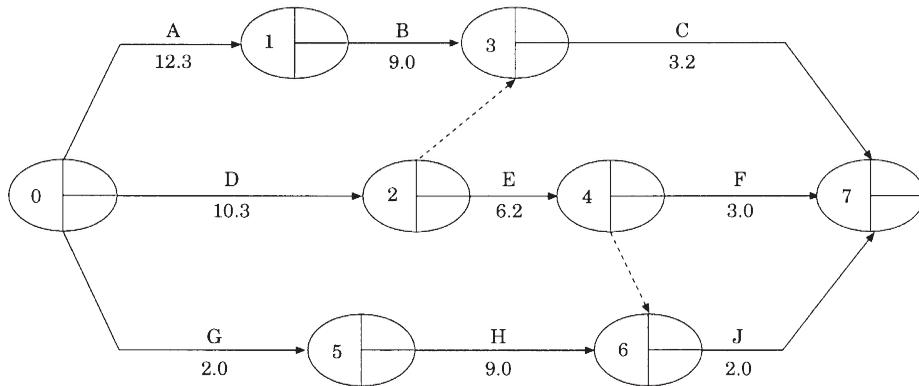
3. Determine critical path. It is obtained by analysing the one-time deterministic model as worked out in **Figure 4.24**.

Transfer deterministic model into PERT network. This is achieved by replacing the one-time estimate with the three-time activity estimates and marking the critical path, as shown in **Figure 4.25**. *Note:* If more than one critical path is discovered during the analysis, then the path having the maximum level of uncertainty is termed as the critical path. The method of measuring uncertainty is covered in the next section.

4.3.3 Uncertainty in Project Duration Estimation

The duration of an activity is defined as the expected economical transaction time. Its estimation is based on the current practices that are carried out in an organised manner under the normal prevail-

Figure 4.24

Determining Critical Path
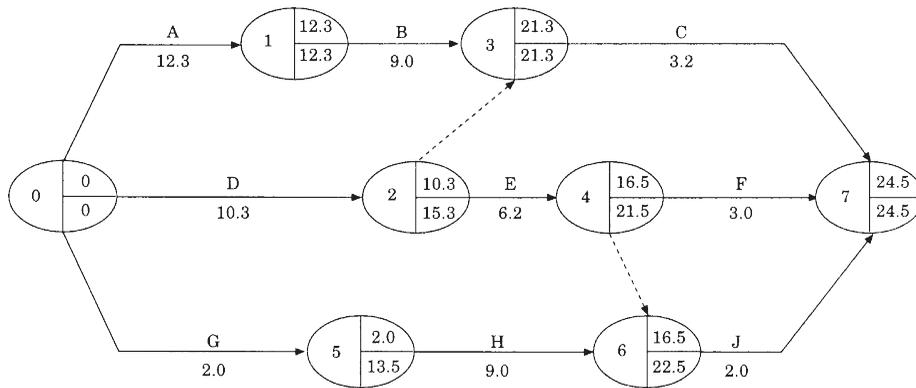
Figure 4.25

Transferring a Deterministic Model into PERT Network
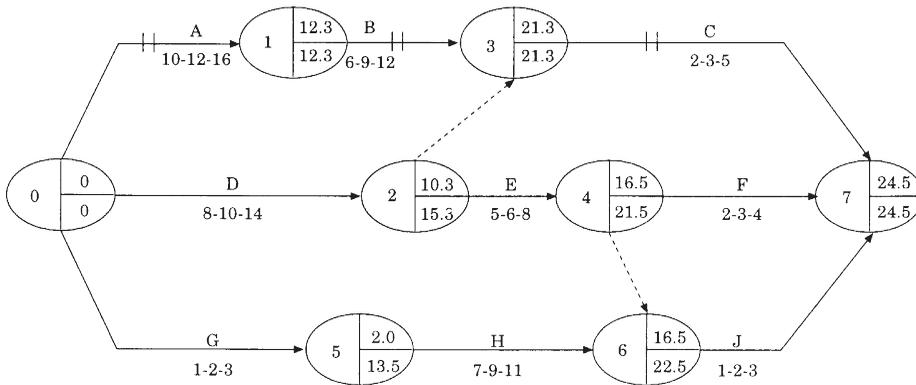
ing conditions at the place of execution. Its assessment is done preferably by the person responsible for its performance.

The duration estimation of an activity, however, cannot be taken as exact. It has fringes, and may be a bit this side or the other. These slight variations add to the uncertainty in the network. When they are considerably less, the one-time estimate is used for activity-duration estimation and determination of resources. To cater to the uncertainty prevalent in activity estimation, the PERT statisticians developed the three-time estimate, assuming that activity estimation trend follows the beta probability distribution (see **Figure 4.26**).

To reduce the number of parameters in the beta distribution and to simplify calculations, it is assumed that the expected activity duration corresponds to the 50% probability of performance. Its value is estimated from:

Figure 4.26

Activity Distribution Curve
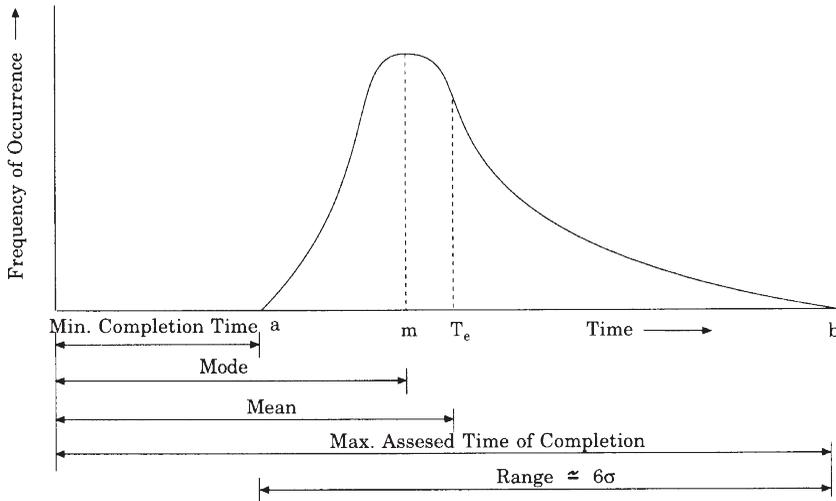
$$\text{Mean value} = \frac{a + 4m + b}{6} = T_c$$

Where,

m is taken as the most likely time, assessed by the planners

a and b are defined as the optimistic and pessimistic times which an activity takes for its performance.

It is assumed that a and b are non-negative and:

$$A < m < b$$

The beta curve is taken as unimodel and continuous. Standard deviation, which is a measure of uncertainty, is taken as $(b - a)/6$. The greater the spread $(b - a)$, the higher will be the value of standard deviation, and more will be the uncertainty.

Consider A and B as two activities of a project.

A	B
$T_o = 4$	$T_o = 1$
$T_m = 7$	$T_m = 6$
$T_p = 16$	$T_p = 23$

For Activity A

$$Te = \frac{T_o + 4T_m + T_p}{6}$$

$$T_e(A) = \frac{4 + 4 \times 7 + 16}{6} = 8$$

For Activity B

$$T_e(B) = \frac{1 + 4 \quad 6 + 23}{6} = 8$$

Standard deviation of Activity, A = (16 – 4)/6 = 2
Standard deviation of Activity, B = (23 – 1)/6 = 3.67

Although the expected performance time of activities A and B is eight, their range (difference between the highest and the lowest value, that is, $T_p – T_o$) differs. The greater the range the higher is the value of standard deviation and higher is it uncertainty.

The duration of a project is computed by adding the duration of activities along a critical path. In order to evaluate uncertainty in project time, the originators of PERT assumed that the means of

Figure 4.27

Pattern of Variation of Project Time
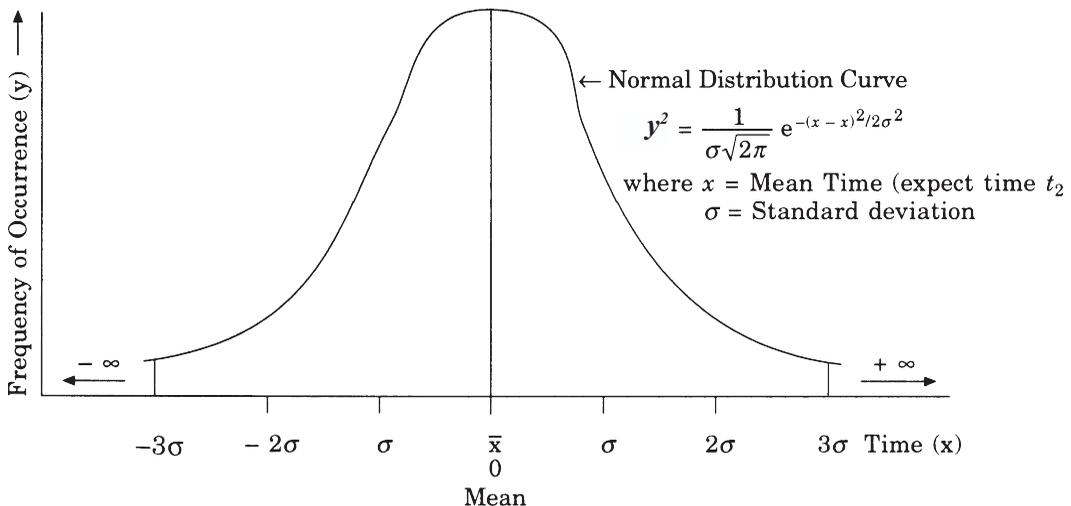
distribution of critical activities, lying on a critical path, follow the normal distribution, and thus, the pattern of variation of project time approximates the normal distribution with the characteristics shown in **Figure 4.27**.

- Mean = Sum of the means of critical activities:

$$\bar{x} = x_1 + x_2 + \ldots\ldots\ldots + x_n$$

> = Expected project duration corresponding to 50% probability.
> = Mean of Normal Distribution

- Variance = Sum of variance o critical activities

$$\bar{V} = V_1 + V_2 + \ldots\ldots\ldots + V_n$$

> = Variance of Normal Distribution

- Standard deviation= √Variance

$$\sigma = \sqrt{\bar{V}}$$

> = Standard deviation of Normal Distribution

It may be noted that a normal distribution curve is fully defined and can be plotted when its mean and standard deviation are known.

To simplify calculations, the effect of variation of non-critical activities is not considered.

Figure 4.28

Time Analyzed PERT Network
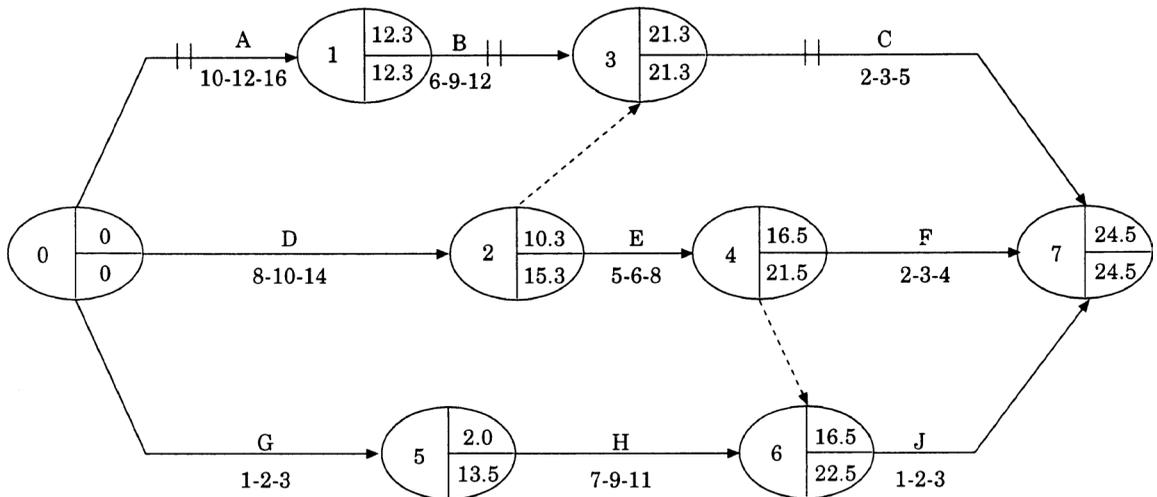
Further, if there is more than one critical path, the path having the maximum variance is used for determining uncertainty.

Example. Consider the case of the PERT network given in **Figure 4.28**.

1. *Expected project duration*. It is given by adding the expected duration of critical activities.

Expected Project Duration $= A + B + C = 12.3 + 9.0 + 3.2 = 24.5$

2. *Standard deviation*. Variance is equal to the sum of variances of critical activities.

$$V = V_a + V_b + V_{ca}$$

$$= \left\{ \frac{16-10}{6} \right\}^2 + \left\{ \frac{12-6}{6} \right\}^2 + \left\{ \frac{5-20}{6} \right\}^2$$

$$= 1.00 + 1.00 + 0.25 = 2.25$$

Therefore, project standard deviation is given by:

$$\sigma = \sqrt{V}$$
$$\sigma = \sqrt{2.25} = 1.5$$

Figure 4.29

Probability Distribution Graph
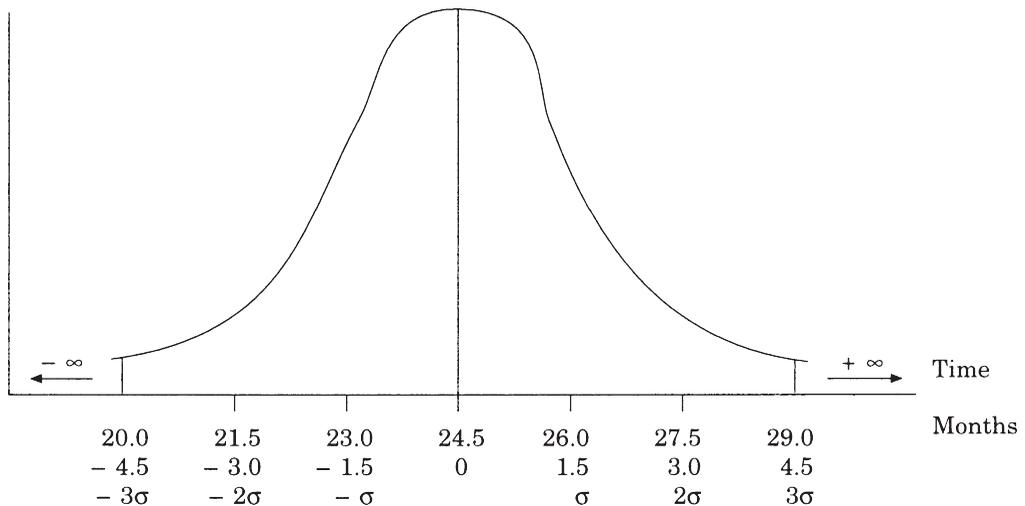
Hence, the normal probability distribution of this project has the following characteristics:

Means = Project duration corresponding to 50% probability

Means = 24.5 Standard deviation = 1.5

The graph of the distribution is shown in **Figure 4.29**.

Figure 4.30

Probability of Project Completion Time at x = Shaded Area of Curve
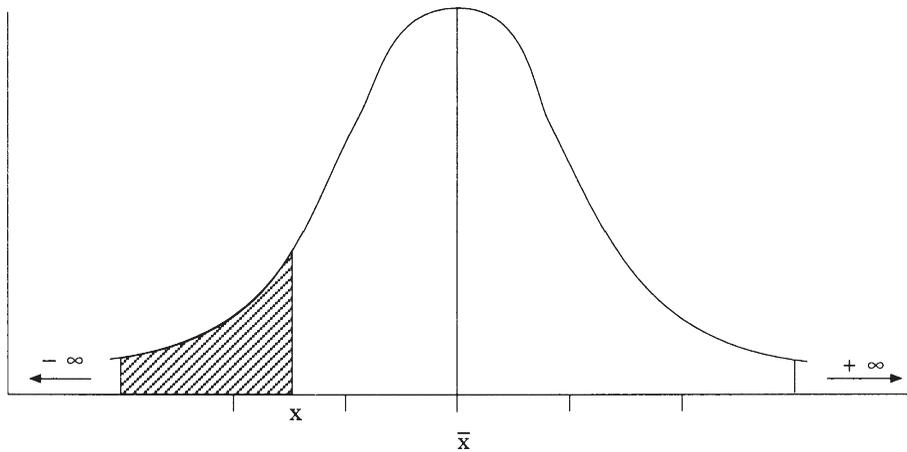
4.3.4 Probability of Meeting a Given Time Scheduling

Unlike the network, using the single-time estimate where the emphasis is on activities and their related cost (or resources), the network using three-times estimates contains information that enables calculation of the probability of meeting a given schedule. The chances of meeting a given project time schedule (say x) are equal to the area of the project probability distribution **Figure 4.30**.

Probability = Shaded area under the curve × 100

The shaded area of the normal distribution corresponding to the value x (expressed in standard deviation units) can be directly read from the standard normal distribution table given in **Table 4.9**. The value of x in standard deviation units (**Figure 4.31**) can be worked out as:

$$x = \frac{\text{Scheduled date} - \text{Expected date}}{\text{Standard deviation}}$$

Example 1: Calculate the probability of completion in 23 months from the probability distribution given in **Figure 4.29**.

$$x = \frac{\text{Scheduled date} - \text{Expected date}}{\text{Standard deviation}} = \frac{23 - 24.5}{15} = -1$$

The normal distribution for the project is shown in **Figure 4.27**, with the value of x marked on it.

The probability of project completion in 23 months is given by the area under the curve corresponding to $X = -1$. Referring to the **Table 4.8** the area under the curve at $x = -1$ gives this probability as 15.87%.

Table 4.9

Area Under the Normal Curve

X	Area		X	Area
− 3.5	0.00023		0.0	0.5000
− 3.4	0.00034		0.1	0.5753
− 3.3	0.00048		0.2	0.6141
− 3.2	0.00069		0.3	0.6517
− 3.1	0.00097		0.4	0.6879
− 3.0	0.00135		0.5	0.7224
− 2.9	0.0019		0.6	0.7549
− 2.8	0.0026		0.7	0.7852
− 2.7	0.0035		0.8	0.8133
− 2.6	0.0047		0.9	0.8389
− 2.5	0.0062		1.0	0.8621
− 2.4	0.0082		1.1	0.8830
− 2.3	0.0107		1.2	0.9015
− 2.2	0.0139		1.3	0.9177
− 2.1	0.0179		1.4	0.9319
− 2.0	0.0226		1.5	0.9441
− 1.9	0.0287		1.6	0.9545
− 1.8	0.0359		1.7	0.9633
− 1.7	0.0446		1.8	0.9706
− 1.6	0.0548		1.9	0.9767
− 1.5	0.0668		2.0	0.9817
− 1.4	0.0808		2.1	0.9857
− 1.3	0.0968		2.2	0.9890
− 1.2	0.1151		2.3	0.9916
− 1.1	0.1357		2.4	0.9936
− 1.0	0.1587		2.5	0.9952
− 0.9	0.1841		2.6	0.9964
− 0.8	0.2119		2.7	0.9974
− 0.7	0.2420		2.8	0.9981
− 0.6	0.2743		2.9	0.9986
− 0.5	0.3085		3.0	0.99900
− 0.4	0.3446		3.1	0.99929
− 0.3	0.3821		3.2	0.99950
− 0.2	0.4207		3.3	0.99965
− 0.1	0.4602		3.4	0.99976
− 0.0	0.5000		3.5	0.99983

Example 2: Estimated project duration corresponding to 98.00% probability of completion from the distribution given in **Figure 4.29**.

$$x = \frac{\text{Scheduled date} - \text{Expected date}}{\text{Standard deviation}}$$

Value of x corresponding to 98% probability as read from **Table 4.9** is 2.0. Hence, the probable completion date is

$$= 24.5 + 2.0 \times 1.5 = 27.5 \text{ months}$$

Figure 4.31

Normal Distribution for the Project
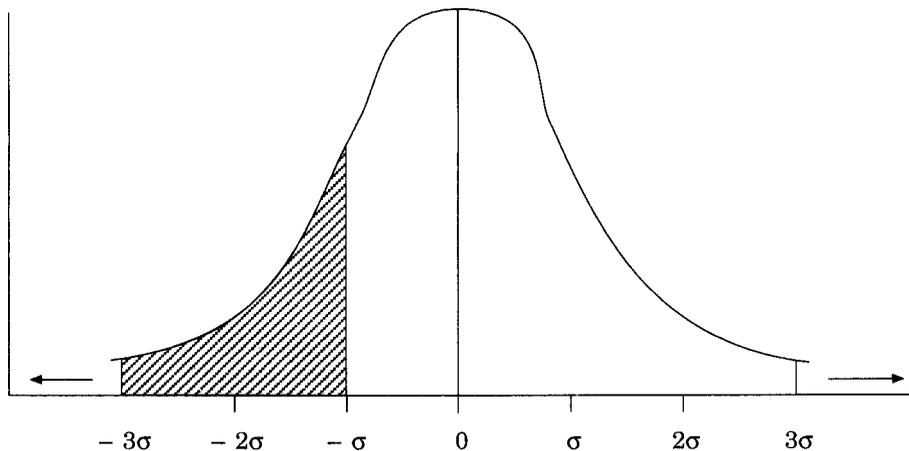
Example 3:   Assess expected duration corresponding to 25% probability in **Figure 4.29**. From **Table 4.9**, the value of x corresponding to 25% probability = –0.675 .Hence, expected date = 24.50 – 0.675   1.5 = 24.50 – 1.01 = 23.49 months.

Note: The procedure used to calculate the probability of meeting a given schedule can be summarised as follows:

Step 1: Determine the expected durations (T_e) of all the activities of the network.

Step 2: Compute critical path, considering the expected duration of all activities.

Step 3: Assess the expected completion time of the project by adding the expected durations of critical activities along a path.

Step 4: Calculate the variance of the project probability distribution by adding variances of critical activities along each critical path. If there is more than one path, take the maximum value.

$$\text{Standard deviation} = \sqrt{\text{Variance}}$$

The standard deviation is a measure of dispersion. The larger the variance. The bigger the spread and more uncertain is the achievement of the scheduled time.

Step 5: Determine the value of abscissa of normal curve in standard deviation units as:

$$x = \frac{\text{Scheduled date} - \text{Expected date}}{\text{Standard deviation}}$$

Step 6: The probability of completing the project in x units of time is equal to the area under the normal curve from $-\infty$ to x. The area under the curve is read from **Table 4.9**. The important values of area under the curve for different values of x are:

$$x = -3\sigma, \qquad\qquad \text{area} = 0.135\%$$

$$x = -2\sigma\, r, \qquad \text{area} = 2.28\%$$
$$x = -\sigma, \qquad \text{area} = 15.87\%$$
$$x = 0, \qquad \text{area} = 50.00\%$$
$$x = \sigma, \qquad \text{area} = 84.13\%$$
$$x = 2\sigma, \qquad \text{area} = 97.73\%$$
$$x = 3\sigma. \qquad \text{area} = 99.865\%$$

Probabilities less than 50% signify the need for using additional resources or effort.

❑ 4.4 PERT VS. CPM

A controversy has developed over the years between the proponents of PERT and CPM. The commonly debated questions are: Which of these methods originated first? Which is the better one? Are both of them practically the same? To understand the various distinguishing features of the two and their spheres of application, let us first discuss their original differences and then the subsequent developments. All controversial issues, which are only of an academic interest with no practical significance have been avoided.

4.4.1 Original Differences

Table 4.10

CPM Vs. PERT Original Differences

	Factors	CPM	PERT
1	Field of application	Deterministic projects like in construction	Projects involving uncertainties like research and development
2	Model emphasis	Activity oriented	Event oriented
3	Activity duration estimation	One-time method	Three-times method
4	Time-cost trade-off	Feasible	Not feasible
5	Resources optimization	Feasible	Not feasible
6	Technique complexity	Simple	Comparatively difficult

CPM was developed for planning, scheduling, and control of *civil works*, while PERT originated in response to the complexities of the uncertainty in *research and development projects* for controlling their multifarious time schedules. Originally, thus, their fields of application were quite different.

In network modelling, CPM laid emphasis on breaking the projects into various works or activities. In PERT, the project breakdown was in terms of milestones which were planned to occur during its execution. Therefore, CPM was *activity-oriented* whereas PERT was *event-oriented*. Originally, the application of CPM was confined to construction works where the activities were

familiar and their duration could be easily estimated from the *one-time estimate*. Since PERT was designed to cope with uncertainties, it used the *three-time estimate*.

In CPM, activity durations were related to costs. This provided a means of assessment of different activity durations with varying costs and made crashing of activities possible. PERT dealt with events and their probable time of occurrence. This enabled adoption of prob-abilistic approach in time scheduling. The CPM schedule enabled optimisation of resources as the activity durations were defined in terms of resources was not possible with PERT. CPM, which used the one-time estimate, was simpler to follow, while, PERT required a stat-istician to interpret the results.

4.4.2 Later Developments

As the various drawbacks of PERT gradually became apparent, series of further studies were initiated by the US Defence Department. Notable among these were the PERT/TIME and PERT/COST. In the CPM field, the concept of three-time estimates was introduced into networks, which were primarily designed for controlling the time factor rather than the resources. In recent years, further developments in PERT and CPM have made CPM appear more like PERT and the subject of network analysis has come to be known as PERT/CPM. To distinguish these two main network techniques, the event-oriented networks using three-time estimates for activity durations having uncertainties can be termed as a PERT network, while, the other, which is activities-oriented that use one-time estimate may be referred to as the CPM. In the high value cost construction project involving uncertainties, Monte Carlo simulation technique can be used to determine probabilities of project completion (see **Appendixes P** and **Q**).

APPENDIX D

PROJECT TIME-COST FUNCTION

❏ D.1   INTRODUCTION

The time and cost factors of a project are inter-related. The project cost function shows the relationship of the cost versus the completion time. Its ordinate represents the cost and the abscissa a time scale. In the formulation of the project cost function, the direct and indirect costs along with the financial gains resulting from early completion are considered..

The project time corresponding to the minimum value of the cost function gives the most economical duration of the project. The project cost function also gives the cost of reducing the project duration from its economical (normal) completion time. Crash point at the interaction of crash time and crash cost; corresponds to the maximum possible time crashing. In addition, project cost func-

tion provides a ready reckoner for assessing the change in cost with varying project duration and resulting critical activities as shown in **Figure D.1**.

Figure D.1

Project Time–Cost Relationship
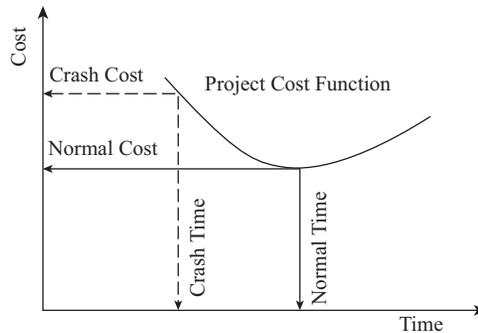
□ D.2   CONCEPT

The basic concept behind the formulation of a project time-cost function is that the normal time duration of an activity is based on considerations of normal cost, using an efficient or desired method of performance of the activity. Each activity is considered in isolation, while working out its normal, time and cost. The reduction in duration below the normal time by a changed method of execution implies an increase in the cost. There will also be a stage beyond which the activity duration cannot be further reduced. The lower limit up to which an activity time can be reduced, is called the crash time and the corresponding cost is referred to as the crash cost.

The difference between the normal time and the crash time of an activity indicates its potential to undergo crashing. The slope of the activity cost function shows the rate of increase of cost, with the reduction in time for the activity as shown in **Figure D.2**.

Figure D.2.

Activity Time Cost Relationship
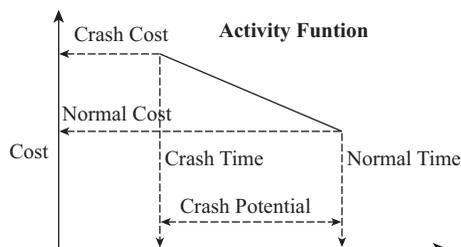
Crashing potential of an activity = Normal time – Crash time.

$$\text{Rate of Crashing} = \frac{\text{Crash Cost} - \text{Normal Cost}}{\text{Normal Time} - \text{Crash Time}}$$

There are number of ways for reducing the activity duration from the normal time depending upon the activity under consideration. The most common methods of time reduction are as follows:

- Increase the resources allotted and/or work overtime; and
- Change the mode of execution/performance of an activity, say from the manual method to the mechanical method.

In some cases, use of several methods of performance of an activity may give a non-linear relation between the activity time and cost, but with a view to simplify the calculations in the formulation of the project cost function. It is assumed that the portion of the curve between the normal point and the crash point is linear.

❑ D.3 PROCEDURE FOR PLOTTING THE PROJECT COST TIME FUNCTION

The procedure for preparation of the least cost schedule is illustrated with the example of a simple project. The network, the activity cost data, assessed crashing costs, and their crashing potential are as shown below. In the given example, the indirect cost is $500 per week and the anticipated bonus for early completion is $800 per week. The step-by-step procedure is also outlined in **Table D.1**.

1. Time analyse the network and deter mine the critical path.
2. Tabulate the normal and crash duration and normal and crash cost for all the activities. Esti-mate the activity-crashing potential for each activity (**Table D.2**).
3. Determine the rate of crashing of all the activities (**Table D.3**).

4. Crash critical activities beginning with the activity having the least rate of crash-ing. Each activity is shortened until its crashing potential is exhausted or a new critical path is formed. If a new critical path is formed, reduce the combination of the critical activities having the combined lowest rate of crashing and continue till there is no more scope for crashing.

| | Lowest Rate of Crashing | |
Activity	Crashing Potential	Rate of Crashing ($)/Week
A	2	1500
B	1	1000

First crashing. With the crashing by one week of Activity B, the cost of the project increases by $1000 and the revised project duration works out to be 9 weeks (see **Figure D.4**).

Table D.1

Procedure for Plotting Project Cost Time Function

1. Time analyse the network and determine the critical path.

2. Tabulate normal and crash duration, and normal and crash cost for all the activities.

3. Estimate activity crashing potential for each activity.

4. Determine the rate of crashing of all the activities.

5 Crash critical activities beginning with the activity having the least rate of crashing. Each activity is shortened until its crashing potential is exhausted, or a new critical path is formed.

6. If a new critical path is formed, reduce the combination of critical activities having the combined lowest rate of crashing, and continue till there is no more scope for crashing.

7. At each crashing incorporates the cost implication in a table.

8. Add direct cost date-wise, and then tabulate its cumulative effect.

9. Assess indirect cost and saving for early completion, date-wise, and tabulate their cumulative effect.

10. Aggregate cumulative effects of direct and indirect costs and the savings for early completion.

11 Plot the data thus obtained, by selecting suitable scale with time along the abscissa and cost along the ordinate axis.

12. The lowest point of the project cost curve indicates the lowest cost and the corresponding optimum completion time

Table D.2

The Assessed Crashed Costs and the Crashing Potential for a Project

S. No.	Activity	Duration in Weeks		Cost (US$)		Crashing Potential (Week)
(Week)		Normal	Crash	Normal	Crash	
1	A	4	2	4000	7000	2
2	B	3	2	3000	4000	1
3	C	2	2	2000	2000	—
4	D	5	3	2000	5000	2
5	E	2	1	2000	4000	1
6	F	1	1	1000	1000	—
7	G	3	2	3000	8000	1
8	H	3	2	3000	5000	1
9	I	2	1	2000	3000	1

Figure D.3

Analysing the Network: Completion Time is 10 Weeks
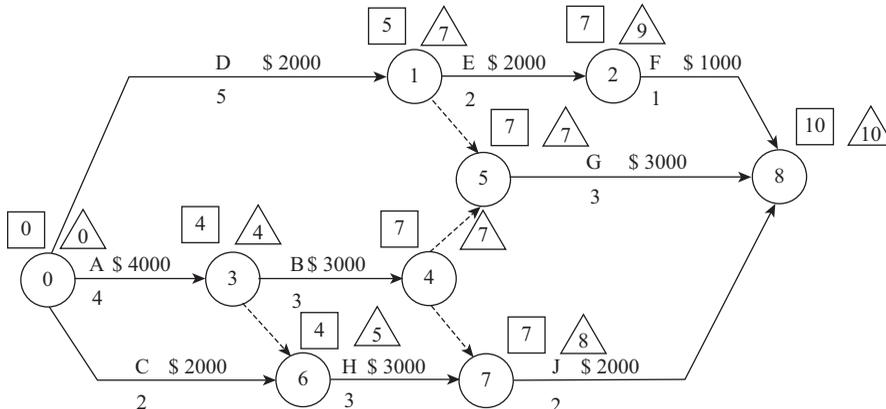
Original Network With Assessed Activity Cost

Table D.3

Determination of the Rate of Crashing

S. No.	Activity	Crashing Potential (Week)	Rate of Crashing (US$) per Week
1	A	2	1500
2	B	1	1000
3	C	—	—
4	D	2	1500
5	E	1	2000
6	F	—	—
7	G	1	5000
8	H	1	2000
9	I	1	1000

Second crashing. Scrutiny of the network after the first crashing reveals that there are two critical paths. Further, reduction means that the sum of the durations of the critical activities along each critical path be reduced by one week. The total increase in the cost for crashing the project duration from 10 weeks to 8 weeks is $2,500, i.e. cost of crashing Activities A and B each by one week (see **Figure D.5**).

Third crashing. The number of critical paths increases after the second crashing. The various ways of reducing the project time during the third crashing are utilised and the revised duration of the activities for 7 weeks completion time is given in the network drawn in **Figure D.6**.

Figure D.4.

Netwok after First Crashing: Completion Time is 9 Weeks
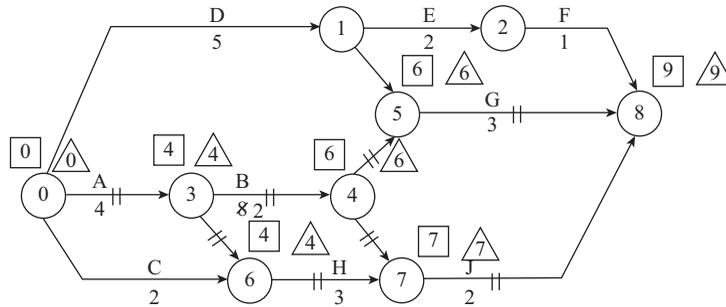
Figure D.5

Netwok after Second Crashing: Completion Time is 8 Weeks
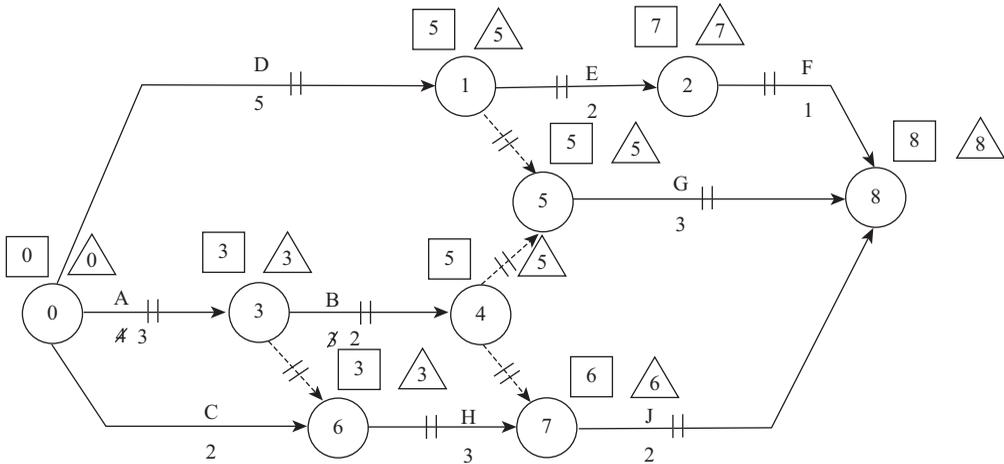
Options	Affected Activities	Determining course of action of reducing project time during third crashing Cost of Crashing (US$)		
1	A & D	1500 + 1500	= 3000	1
2	E, G & J	2000 + 5000 + 1000	= 8000	2
3	E, G & H	2000 + 5000 + 2000	= 9000	3
4	A, E & G	1500 + 2000 + 5000	= 8500	4
5	D, G & J	1500 + 5000 + 1000	= 7500	5

Figure D.6

Network after Third Crashing: Completion Time is 7 Weeks
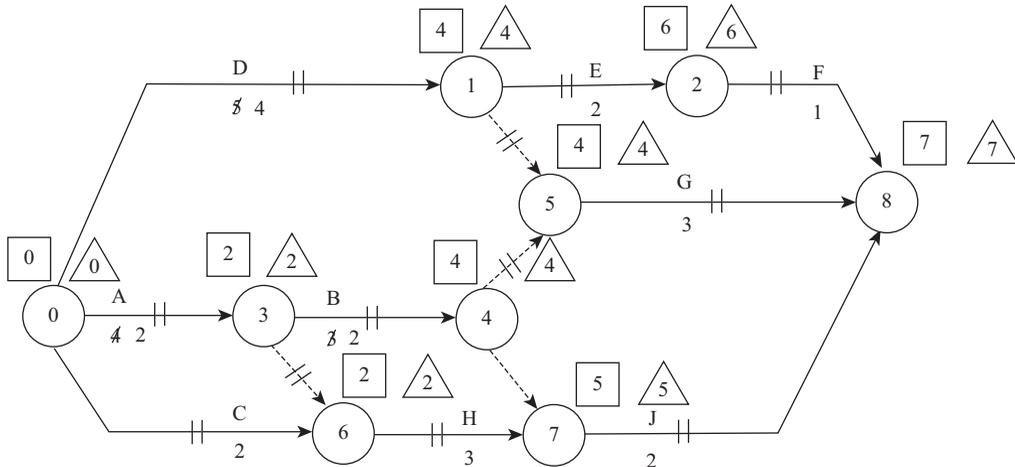
Fourth crashing. Proceeding similarly, it can be easily verified that although all the activities are critical, there is still room for crashing. It may be noted that after the fourth crashing, although activities E and H can be reduced, further crashing of all the critical paths is not possible. Therefore, the fourth crashing becomes the final crashing (see **Figure D.7**).

Figure D.7

Network after Fourth Crashing Completion Time is 6 Weeks
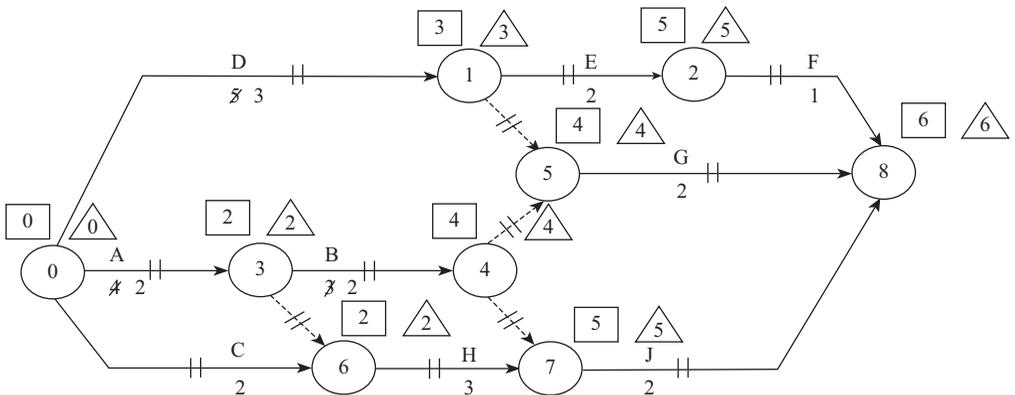
5. Incorporating the cost implication in a table after each crashing. The network, after its fourth crashing, shows the duration of the crashed activities and depicts the network plan of the

least cost of the project. The cumulative effects of direct and indirect costs and the savings for early completion must be aggregated (**Table D.5**).

Least cost schedule. The data, thus obtained, must be plotted by selecting a suitable scale with time along the abscissa, and cost along the ordinate axis. The lowest point of the project cost curve indicates the lowest cost and the corresponding optimum completion time. The project cost-time function generally takes the shape of a concave curve as shown above. The ordinate of the lowest point in the curve gives the most economical cost of the project, and the time corresponding to the least value ordinate gives the optimum duration of the project. The optimum duration for the project under consideration comes out to be 9 weeks and its optimum cost works out to be $267 000 (see **Figure D.8**). Its implication are given in **Table D.4**.

Figure D.8.

Time Cost Trade-Off Function
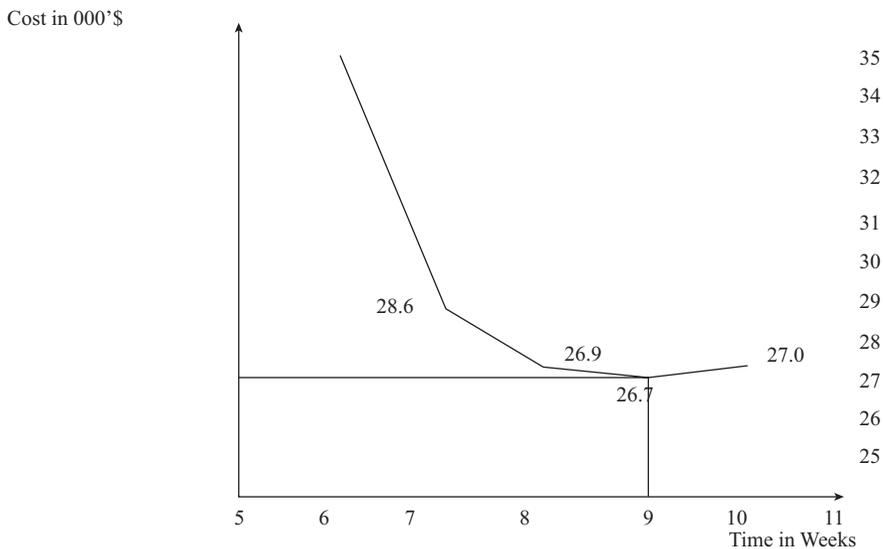
❑ D.4 TIME CRASHING

The project cost curve, which shows the pattern of the cost variation with time, provides a ready reckoner for assessing the increase in cost for a given project duration. All crash points correspond to the maximum possible time crashing. The crashing cost can be determined from the project cost curves. In addition, the tabulated data gives the information regarding the corresponding critical activities and their revised duration. To quote an example, the implications of completing the project in 7 weeks (**Figure D.6**) are:

Table D.4

Detrmination of the Rate of Crashing

Project Duration Crashing (Week)	Crashing Cost Per Week from No Crashing State						
Activity	Reduction Possible	Rate of Crashing	No Crash	First Crash	Second Crash	Third Crash	Fourth Crash
			10 W	9 W	8 W	7 W	6 Weeks
A	2	1500			1500	1500	
B	1	1000		1000			
C	–	–				1500	1500
D	2	1500					
E	1	2000					
F	–	–					
G	1			5000			5000
H	1			2000			
J	1			1000			1000
Crashing cost				1000	1500	3000	7500
Cumulative crashing cost				1000	2500	5500	13 000
Normal cost			22,000	22 000	22 000	22 000	22 000
Indirect cost			5000	4500	4000	3500	3000
Total cost			27,000	27500	28 500	31 000	38 000
Gains for early completion				800	1600	2400	3200
Net financial effects			27,000	26 700	v	28 600	34 800
Project duration in weeks			10	9	8	7	6

Estimation of economical cost for 9 weeks completion	= $26 700.00
Assessed cost for 7 weeks completion	= $28 600.00
Increase in cost due to crashing by 2 weeks	= $1900.00

The revised durations of the critical activities after third crashing are shown in the network (**Figure D.6**).

❏ D.5   A WORD OF CAUTION

There are many benefits, which can be achieved by the early completion of the project. The early project completion can yield added revenue, early release of capital and facilities, and, in some

cases, can save idle time expenses of machinery. The non-financial gains can be earning goodwill, boosting of the reputation, and raising of morale. But the technique of minimising the cost by crashing of activities, although mathematically feasible, as explained, has many inherent practical difficulties. One of the main reasons, is that it is not possible to predict the activity cost-time data accurately. In addition, the advantage gained by economising the project cost is nullified, by the fact that optimisation of resources becomes extremely difficult, resulting in increased cost and resource wastage.

Note: Time crashing networs problems can also be solved using 'Excel-Solver' software.

Precedence Network Analysis

In Critical Path Method and Program Evaluation and Review Technique (CPMT/PERT) networks, activities are connected with each other, according to the finish-to-start logic, i.e. an activity starts only after its preceding activity is completed. But in reality, a certain lag or lead of time between the adjoining activities may occur. While, lag implies a delay in the start of successor activity, on the other hand, the lead allows an overlap of time between successor and its predecessor activity or the amount of time the successor activity can be advanced with respect to predecessor. For example, in a housing construction project, the CPM network may show the activity of wall plastering as starting after the completion of masonry work of a particular building. In practice, however, plastering can start as soon as the masonry in first room is complete and need not wait for completion of masonry work of all the rooms. Such inaccuracies in a CPM network may misrepresent the real time situation unless a detailed CPM network is drawn that includes each minor operation and process. A detailed CPM network, on the other hand, may become unmanageable and defeat the very purpose of project planning.

Each activity in a precedence network (PN), is generally represented by either a rectangular or a square box. These boxes represent activities-on-nodes, unlike the CPMT/PERT networks, which show activities-on- arrows. The time duration of the activity is incorporated inside the nodal box. A precedence network (PN) incorporates the concept of lags and leads, while depicting the relationship of various starts and finish of activities. They represent a real time plan, which shows the dependency and inter-relationship of various activities in a better way as compared to the other project network analysis techniques. The PN is thus best suited for planning complex construction projects. Precedence Network Analysis (PNA) technique is also commonly known as Precedence Diagramming Method (PDM) or Activity-on-Node Network.

This chapter is divided into the following sections:

1. Precedence Network Analysis (PNA) Fundamentals
2. Network Development Procedure

3. Case Illustrations
4. Classification of Networks
5. Guidelines for Drawing Project Precedence Network
6. PNA vs. CPM

Decision Network Analysis is covered in **Appendix E**. Project networks can be easily developed and analysed using Project Management Software; this aspect is outlined in **Appendix F**. Critical Chain Method is explained in **Chapter 16**. Introduction to probability distributions and application of Monte Carlo Simulation technique for analysing non-linear duration activities networks are outlined in **Appendix P**.

❑ 5.1 PRECEDENCE NETWORK ANALYSIS FUNDAMENTALS

5.1.1 Typical Precedence Network

The activities in a precedence network (PN) are depicted by either a rectangular or a square box. The time duration of the activity is incorporated inside the nodal box. The logic relationship in a PN is shown by connecting activity nodes with lines drawn from the preceding activity(ies). The Precedence Network of construction of the raft foundation of a building, is shown in **Exhibit 5.1**. The modeling features of the precedence network are given in the subsequent sections.

Note.

$$\text{Latest Finish Date (LFD)} = \text{Latest Finish Time (LFT)},$$
$$\text{Total Float} = \text{Latest Finish Time (LFT)} - \text{Early Finish Time (EFT), or}$$
$$= \text{Latest Start Time} - \text{Early Start Time}$$

5.1.2 Modelling Features

Activity representation.   Precedence network depicts activities either by square or rectangular nodes, which comprises the activity data. A typical activity box is given below:

EST	Dur	EFT
	ACTIVITY DESCRIPTION	
LST	No.	LFT

The activity description is written in the middle portion of the node box. The duration is written in the rectangular space above it, while the activity number is written inside the box.

The activity data in the box also includes activity timings. The box shape and the data inside the activity box can be represented in different ways (**Figure 5.1**).

LFT	=	Latest Finish Time
Dur	=	Duration
No.	=	Activity number or identification label

Exhibit 5.1

Precedence Network of the Raft of a Foundation

Activity Legend

	Description Code	
EST	Dur	EFT
LST	No.	LFT
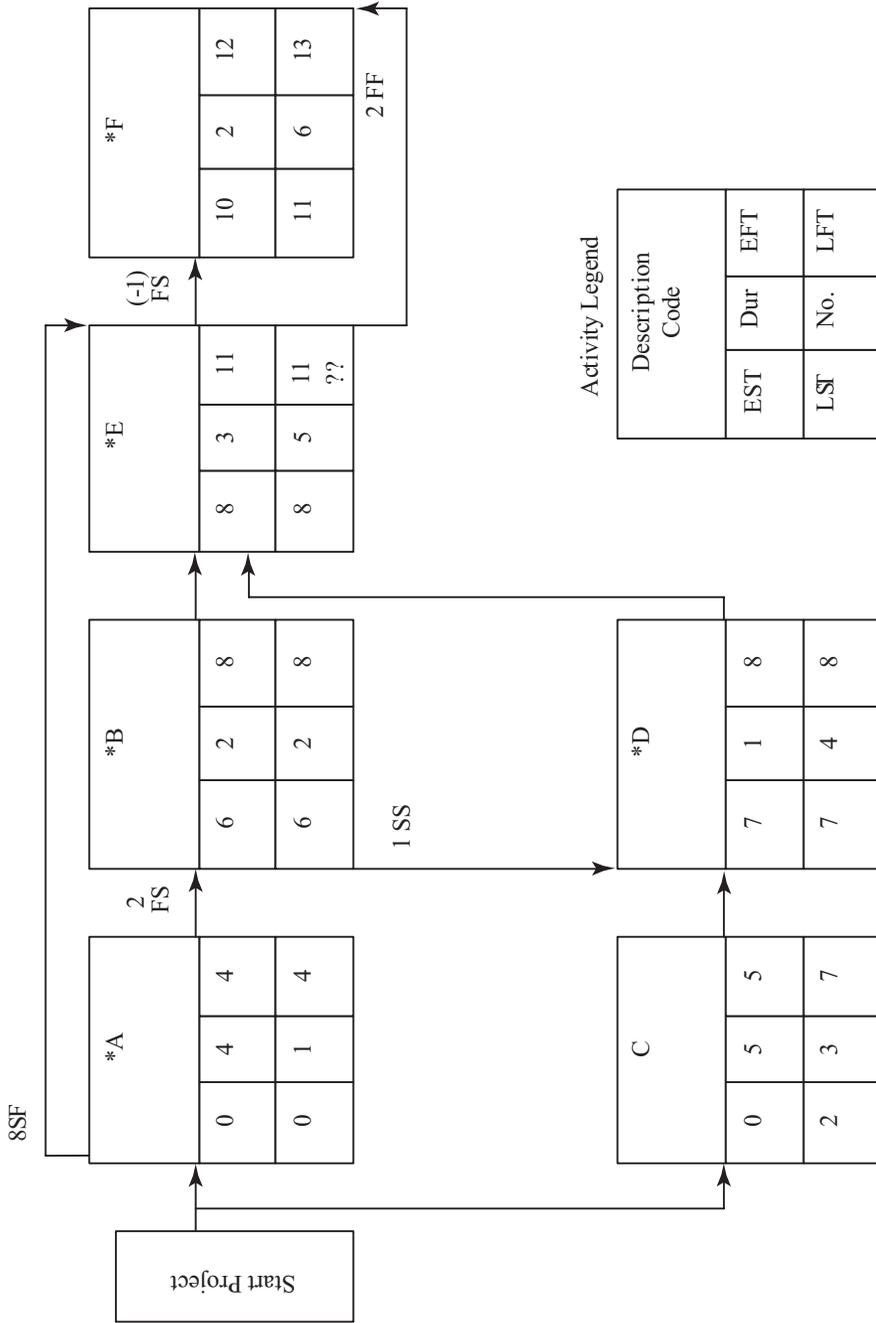
*   Critical Activities
.   Constrain imposed

Figure 5.1

Different Ways of Representing an Activity in PNA

EST	Dur	EFT
DESCRIPTION RESOURCE		
LST	No.	LFT

EST	Dur	EFT
NO. & DESCRIPTION RESOURCE		
LST	TF	LFT

DESCRIPTION RESOURCE		
EST	Dur	EFT
LST	No.	LFT

EST	EFT
DESCRIPTION RESOURCE	
Dur	TF
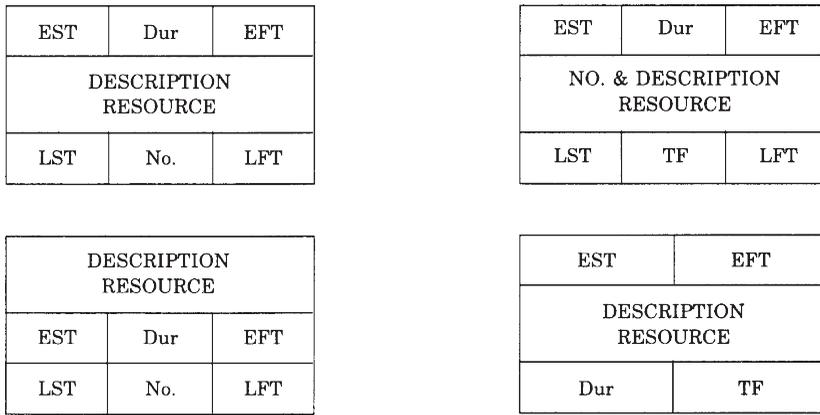
TF = Total Float

Resource = Gang size or man-days or cost earned value etc. can be written below description, if considered necessary.

Network logic. Generally, the extreme left vertical side of the activity box represent the start of the activity; while, on the other hand, the extreme right side, its completion. The connecting lines show the relationship among the various activities. A logic diagram showing the start of activity B after completion of activity A is shown below:

A		B

The logic between the activities is showed by connecting them with lines, where length of lines is insignificant. Generally, these lines move from left to right direction. Arrow heads are not normally shown unless considered essential for clarity of logic. Crossing of lines should be minimised. Where unavoidable, line crossings may be depicted with symbols like those used in electrical circuits.

In PN, the precedence logic between activities is of two types; namely, job dependency logic and construction situational constraints logic:

Precedence Logic

Job Logic
(Mandatory)

Situational
Constraints
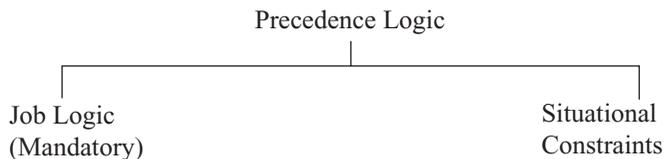
The *job dependency* logic shows the sequence in which the jobs or activities progress, e.g. blinding activity starts after the completion of excavation. It generally follows the rule that except the start activity, each activity can start only after, its preceding activity(ies) is completed.

The *construction job time constraints logic* arises from the restrain on start and completion of dependent activities that is imposed due to the construction process at site. It is of two types, i.e., 'Lag' or 'Lead', which are situational requirements. Lag is a delay between linked job logic activities, while, Lead is an opposite of Lag, i.e. it shows an overlap between preceding and succeeding activity and is shown by assigning negative (–) sign. Most Project Management software do display lag or lead on the network display. No resource is been consumed by Lag or Lead process.

For example, the start of blinding activity may get delayed by two days after completion of excavation for grading and soil testing of the excavated surface. It can be represented on the network by +2FS. This feature of Precedence Networks enables depicting of real time *situational constraints*. The construction situational constraints can be of the following types (**Figure 5.2**).

Figure 5.2

Types of Precedence Relationship

Finish-to-start i.e. delay from the finish of preceding activity to the start of the succeeding one.	A —— 2FS —— B Activity B Starts after 2 time-unit delay constraints from completion of Activity A
Start-to-start i.e. delay from the start of preceding activity to the start of the succeeding one.	8SS A F Activity F starts after 8 time-unit delay constraints from commencement of activity A
Finish-to-finish i.e. delay from the finish of preceding activity to the finish of the succeeding one.	E F 1FF Completion of activity F will take at-least one time unit after completion of activity E
Start-to-finish i.e. delay from the start of preceding activity to the finish of the succeeding one.	B E 1SF D Activity D is finished after at least 1 time unit delay from start of activity B
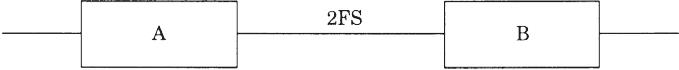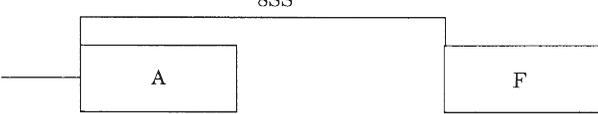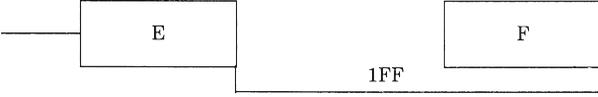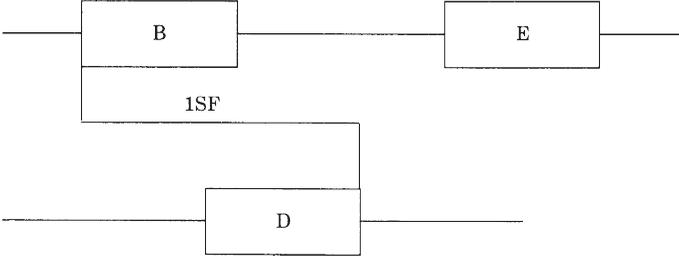
Note: Situational relationships are always defined from preceding activity to its successor activity.

Representation of situational constraints on starting and finishing activities, which is generally stated in terms of time delays, is a unique feature of PN. Unlike CPM/PERT networks, PN depicts the lead or lag in activities to provide a realistic sequence of engineering tasks as they occur in the actual execution of works. CPM/PERT networks use only FS situational constraint.

Note: In complex networks, a dummy can be introduced to simplify crisscrossing of linkage. Using a dummy connector/event in order to link multiple activities can avoid congestion. Dummy events can be drawn as boxes or circles.

❑ 5.2 NETWORK DEVELOPMENT PROCEDURE

5.2.1 Network Development Procedure

Though the procedure for drawing PN is similar to CPM, its model presents a different look. For the beginners, the step-by-step network modeling procedure involves defining the network scope, listing activities, developing logic diagrams, structuring networks, incorporating activity duration, superimposing lead or lag constraints, and finally, numbering the various activities. The procedure is illustrated with the example of Precedence Network of construction of the raft foundation of a building. It is shown in **Exhibit 5.1**.

Raft Construction methodology.   The various activities involved in the raft construction are given in **Table 5.1**.

Table 5.1

Various Activities of the Raft Construction

Code	Description	Duration (days)
A	Excavation	4
B	Blinding base	2
C	Steel fabrication	5
D	Transportation of rebar steel to task	1
E	Formwork setting and rebar fixing	3
F	Raft concreting	2

Excavation starts with the commencement of the building construction and takes four days to complete. After excavation, two days lag is required to clear the area, conduct compaction tests, and mark the layout prior to the commencement of blinding.

Excavation is then followed by blinding, i.e. placing of lean concrete on the base. This is completed in two days. The raft formwork and reinforcement steel bar fixing is commenced after the blinding of the base.

Formwork and steel fixing is finished in three days, after the completion of blinding. Procurement and fabrication of steel required for the raft can start at the fabrication shop on commencement of the building construction, which can take upto five days. However, fabricated steel can be transported from the workshop to task, only after when part of the blinded area is cleared of the excavated material, which is expected to take one day from the start of blinding process. Further, due to constraints regarding the availability of a crane, unloading at site, which is a part of this transportation activity, must be completed the same day.

The formwork setting and fixing of reinforcement proceed concurrently that gets complete in three days. The expansion joint in the middle of the raft divides this work into two parts; where the first part takes two days for completion and the second, third day, which gets followed by raft concreting.

Raft concreting is also subject to approval of concrete mix compressive strength that is determined by testing concrete cubes, which is scheduled on the eighth day from the commencement of building excavation. The process of concrete placing takes two days. Concreting can start one day prior to finish of the first part of the preceding activity of Formwork and Steel fixing, i.e. 2 days from the start of Formwork and Steel fixing. It is subject to the condition that LFT of Formwork and Steel fixing must be completed latest by *11 days to enable its movement to the next raft and concreting, thereafter takes 2 days*.

Defining the network scope.   Generally, a PN starts with a single 'start node' and terminates on a single 'final node'. In cases, where there are more than one activity starting in the beginning or terminating at the end, an additional activity node is inserted. In **Exhibit 5.1**, start project node is inserted since the two activities (activity A and activity B) start concurrently in the beginning of the project.

Activity listing and activity dependence table.   This can be prepared in a manner similar to CPM network, as shown in **Table 5.2**.

1. *Note 1*: After finishing excavation (activity A), it takes two days to clear the area, conduct compaction tests and mark the layout, i.e. 2 FS, prior to start of blinding of base (activity B).
2. *Note 2*: Transportation of fabricated steel after finish (completion) of steel fabrication in the workshop can commence one day after the start of part of the blinding area (expected to take one day from start of blinding) is cleared of the excavated material. This is to be com pleted on the same day as its duration is 1day.
3. *Notes 3*: Raft concreting in the first part of the blinded area, can start one day prior to finish of the formwork and rebar activity. However, finish of concreting of the remaining part will take one day after finish of formwork and rebar activity.
4. *Note 4*: Raft concreting is subject to approval of the concrete mix 7-day compressive strength determined by testing concrete cubes, which is scheduled on the eighth day from the commencement of excavation.
5. *Note 5*: Network can be drawn easily on computer screen using project management software like Primavera and Microsoft (see **Chapter 16** and **Appendix P**).

Table 5.2

Activity Listing and Activity Dependence

Activity	Code	Preceding	Succeeding	Situational Constraints		
				Type	Extent	Activity(s) Preceding
Start	S	-	A, C	-	-	-
Excavation	A	S	B, D	FS	-	S
Blinding base	B	A	E	FS	2	A (Note-1)
Steel fabrication	C	S	D	-	-	S
Rebar transportation	D	C, A	E	SS	1	B (Note-2)
Formwork and rebar	E	B, D	F	-	-	-
Raft concreting	F	E	-	FS	(−1)	E (Note-3)
				FF	1	E (Note-4)
				SF	8	A (Note-4)

6. *Note 6*: In order to prevent crisscrossing of lines, dummy connectors can be inserted, as shown in **Figure 5.3** and **Figure 5.6** .

Precedence logic diagram.   The first step while drawing the network is to establish network logic, either by making an activity dependence table or with experience by directly sketching the network outline. In PN, a flow diagram can be easily plotted on pre-printed box pattern drawing sheets, tracing papers, or box type stickers, similar to that of box pattern sheet. Each box can represent an activity and the flow diagram can be developed by connecting these boxes logically with lines. The left-side of the activity box represents the start and its right side represents the end of an activity. Finish also marks the exit point of an activity. The top and bottom of the box are kept off-limit, unless required to connect activities with other sub-networks. It is shown in **Figure 5.4**.

Network drawing.   The formal PN can then be drawn by using the standard symbols and network drawing conventions as shown in **Exhibit 5.1**.

Duration estimation.   The duration of an activity in PN is assessed generally by the one-time estimate method. Generally, delays are expressed in terms of time units, though they can also be reflected as percentage of the preceding activity duration. In the later case, the percentages have to be converted to time units for the purpose of time analysis.

The three-times estimate of activities can also be used in PN. In such cases, analysis of the network is carried out by reducing three-times to a single expected time and then proceeding in a manner similar to PERT.

Figure 5.3

Dummy Connectors to Link Precedence Activities
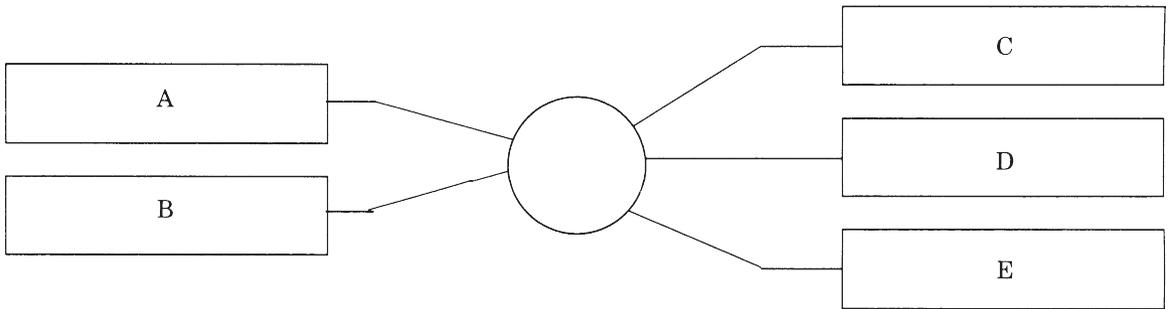
Figure 5.4

Precedence Logic Diagram
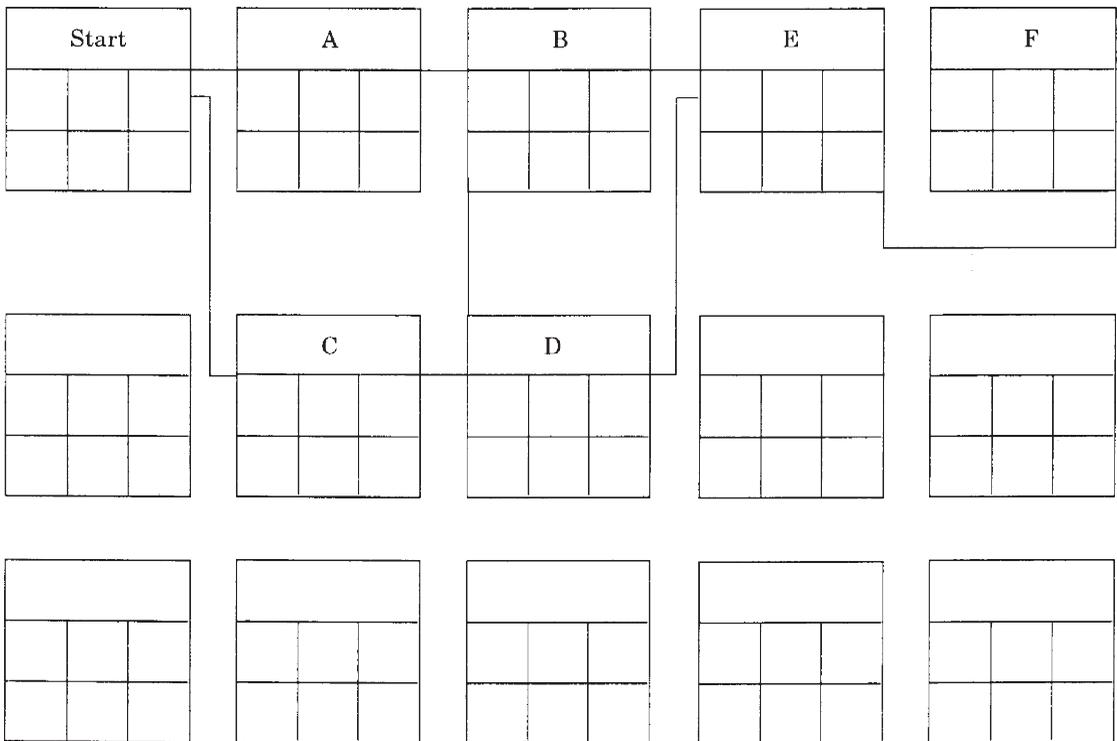
Activity numbering.   The activity numbering methodology is similar to CPM numbering. It commences with the start of an activity and completes with the last one. This labelling is primarily

done for manual time analysis. Project management software generally provides 10 characters or more space for labeling activities that are called as Identification Codes (ID). Designing of an activity identification code is covered in **Chapter 18**.

Project network. The project network is developed by logically integrating its sub-networks. It covers the entire project scope and depicts its execution plan. It also highlights the milestones and contracts or sub-contracts that are been planned during the project life. It provides the yardstick for measuring and analysing progress. It is supported by the various sub-networks of the project. The left-side of the activity box represents the start and its right side represents completion or end. Finish also marks the exit point of an activity. The top and bottom of the box are kept off-limit unless required to connect activities with other sub-networks.

Integration of sub-network logic commences from the beginning of the project. While integrating, the sequence of activities is verified by its preceding and succeeding activities. Work packages falling in the same strata are connected based on the occurrence order. The integrating process finishes, when each activity within or outside, the sub-network is logically linked with precedence logic lag and lead amount, wherever applicable.

If these are flaws in developing a network, the project schedule will become unrealistic. Most common flaw is assuming limited resources and linking every activity with SS and FF logic. Assume unlimited resources and use precedence logic, unless there is a specific constraint. The issue of resources optimisation is resolved during scheduling.

5.2.2 Time Analysis

In PN, the activity times and not the event times are shown on the network. Like CPM network, the time analysis process can be divided into two stages, namely, forward-pass computation and back-pass computation. These timings facilitate determination of critical path and various types of floats. The method of time analysis of raft concreting network drawn in **Exhibit 5.1**, like CPM networks, involves forward path and back pass, whichis given in following paragraphs.

Forward-pass computation. Set the Earliest Start Time (EST) of nodes that depicts the start of the project as zero and write it in the space provided. Nodes shall follow in the ascending numerical order.

a. *Activity A node No. 1*

$$EST1 = 0$$
$$EFT_1 = EST_1 + d_1 = 0 + 4 = 4$$

b. *Activity B Node No. 2*

$$EST_2 = EFT_1 + delay = 4 + 2 = 6$$
$$EFT_2 = EST_2 + d_2 = 6 + 2 = 8$$

c. *Activity C Node No. 3*

$$EST_3 = 0$$
$$EFT_3 = EST_3 + d_3 = 0 + 5 = 5$$

d. *Activity D Node No. 4*

$$EST_4 = (EFT_3) \text{ or } (EST_2 + 1SS), \text{ greater of these}$$
$$= 6 + 1 = 7 \ EFT_4 = (EST_4 + d_4) = 7 + 1 = 8$$

e. *Activity E Node No. 5*

$$EST_5 = \text{Greater of } EFT_4 \text{ and } EFT_2$$
$$= \text{Greater of 8 and 8}$$
$$= 8$$
$$EFT_5 = \text{Greater of } EST_5 + d_5 = 8 + 3 = 11$$

f. *Activity F Node No. 6*

$$EST_6 = \text{Greater of } EFT_5 - 1, \text{ and } EST_0 + 8,$$

As a specific case concreting can start after 10 days subject to completion of the half raft upto expansion joint, raft is divided into two equal parts by the expansion joint and it need not wait till completion of second part. However, the latest the time for completion of formwork and steel fixing is 11.

$$= 11 - 1 \text{ FS, and 8; greater of these,}$$
$$= 10$$
$$EFT6 = EST6 + d6 \quad \text{or} \quad EFT5 + 1, \text{ whichever is greater}$$
$$= 10 + 2 \text{ or } 11 + 2 = 13.$$

This situation has arisen because of the constrain that that LFT5latest finish time is 11 (due to imposed constrain) and concreting must start thereafter.

Back-pass computation. Proceeding systematically with nodes in descending order, results in working out of the latest timings of the activities, as shown in **Table 5.3**.

Table 5.3

Nodes and Timing Activities

Node No.	Activity	Duration	LFT	LST
6	F	2	13	10
5	E	3	11▲	8
4	D	1	8	7
3	C	5	7	2
2	B	2	8	6
1	A	4	4	0

Critical path (CP).   It refers to the path of activities, whose duration is the longest. Activities A, B, E, and F have zero float (Float = LST –EST), and are critical activities. The path from start to end connecting these critical activities is known as the critical path. The length of this longest path in the network is 12 time units.

Schedule dates are obtained by adding 'one' to EST and LST. The timings in network can be shown in scheduled dates using the following rule:

$$\text{Early Start Date (ESD)} = \text{Early Start Time (EST)} + 1$$
$$\text{Latest Start Date (LSD)} = \text{Latest Start Time (LST)} + 1,$$
$$\text{Early Finish Date (EFD)} = \text{Early Finish Time (EFT)},$$
$$\text{Latest Finish Date (LFD)} = \text{Latest Finish Time (LFT)},$$
$$\text{Total Float} = \text{Latest Finish Time (LFT)} - \text{Early Finish Time (EFT), or}$$
$$= \text{Latest Start Time} - \text{Early Start Time}$$

Changing all timings to scheduled dates can be a solution; however, it is preferable to analyse by making use of timings and dates during scheduling. If you are working with project management software, check which mode of network analysis is displayed by it.

5.2.3   Repetitive Works Network

The PNA technique can be applied to prepare the network plan of projects that involves repetitive works. Such networks also facilitate scheduling of manpower as well as other resources.

As an example, take a building complex involving construction of four similar raft foundations. The work scope and network for completion of the first raft is given in **Exhibit 5.1**. This network indicates that the first raft takes two working weeks for completion; assuming that rebar steel fabrication would be carried out in the central rebar fabrication yard. The network for construction of subsequent rafts can be easily developed as follows:

- Decide the order of priorities of constructing rafts; and
- Plan each construction activity into a work-team with the assigned manpower, equipment and other resources that are required for its completion.

The raft-construction network plan can then be developed by vertically linking the work-teams (**Exhibit 5.2**). In particular, the backward-pass time calculations should be thoroughly scrutinised. Note that one work-team for each activity continues working on similar activities of subsequent rafts till the time of completion. This example highlights the usefulness of using PNA network technique for planning repetitive works project.

❑ 5.3   CASE ILLUSTRATIONS

5.3.1   Primary School Construction PN

This illustrates the methodology of developing the network for construction of a primary school by integrating its sub-networks, summarising this network by introducing hammock activities, and

Exhibit 5.2

Four Rafts Construction

8 SS

RAFT No. 1

Excavation			2 FS	Blinding				Formwork & Rebar			−1 FS	Concreting		
0	4	4		6	2	8		8	3	11		10	2	12
0	1	4		9	2	11		11	3	14		16	4	18

RAFT No. 2

Excavation			2 FS	Blinding				Formwork & Rebar			−1 FS	Concreting		
4	4	8		10	2	12		12	3	15		14	2	16
4	5	8		12	6	14		14	7	17		18	8	20

RAFT No. 3

Excavation			2 FS	Blinding				Formwork & Rebar			−1 FS	Concreting		
8	4	12		14	2	16		16	3	19		18	2	20
8	9	12		15	10	17		17	11	20		20	12	22

RAFT No. 4

Excavation			2 FS	Blinding				Formwork & Rebar			−1 FS	Concreting		
12	4	16		18	2	20		20	3	23		22	2	24
12	13	16		18	14	20		20	15	23		22	16	24

preparing the network of a group of similar educational buildings. The primary school building is broadly divided into three parts; Wing 1, Wing 2, and gymnasium. Wings 1 and 2 have a common foundation, and both are two-storied. The roof of the gymnasium is supported on portals. The Wing

2 and gymnasium share a common beam with the gymnasium roof starting a week later than Wing 2 roof. The construction of school involves the following stages:

- Foundation of Wing 1 and Wing 2 up to the ground floor slab;
- Foundation of gymnasium portal to start eight weeks after the commencement of the foundation of wings. It is due to site constraints;
- Frame structure of Wing 1, Wing 2 and gymnasium; and
- Block work and finishes.

The primary school Work Breakdown Structure is shown in **Exhibit 3.6**. After examining the construction methodology and the sequence and logic of activities; the PN of the primary school can be developed by integrating the following logic sub-network diagrams:

Foundation Wing 1, Wing 2 and gymnasium activities

1. Foundation portals gymnasium   EF
2. Ground floor slab   PB
3. Plinth filing   PF
4. Stub column and plinth beam   GS
5. Excavation and footing   FP

Frame structure of Wing 1, Wing 2 and gymnasium activities

6. First floor column Wing 1   FC
7. FF slab and beam Wing 1   FS
8. Roof structure Wing 1   RS
9. First floor Wing 2   FF
10. Construction portals   CP
11. Slab of gymnasium and Wing   SG

Block work and finishes

12. Block work   BW
13. Pipes and conduit, and frames   PC
14. Internal plaster   IP
15. Ducting and wiring   DW
16. External plaster   EP
17. Roof treatment   RT
18. Screed   SC
19. Tiling   TL
20. Preliminary paint treatment   PT
21. Air-conditioning equipment
    Installation and testing   AC

22. Carpentry and Joinery   CJ
23. Fittings, fixtures and metal works   FM
24. Final Paint and Completion   CM

The integration of work-package logic diagrams in construction sequence produces the project logic diagram. The flow diagram of the primary school construction shows box type activities and the logic build-up is shown in **Figure 5.5**.

The project flow diagram can be converted to PN by using the network drawing rules similar to that of CPM. The primary school structure construction precedence sub-network is shown in **Exhibit 5.3**. Similarly, the 'finishes', sub-network can be added to the structure construction sub-network to develop the primary school construction network.

The summarised network of the primary school project is shown in **Exhibit 5.4**. This network, in addition to controlling the work progress, was also used to prepare the network plan for a group of educational buildings in the 2000 Housing Units Project. This project involved construction of a nursery, a kindergarten, a primary, and a high school on the western sector of the project area. These sch ools were of similar design and construction but varied in construction areas. The activities and their durations, school-wise, are reflected in **Exhibit 3.7**.

Taking into consideration the development plan, the priorities for completion of the construction of schools were determined. Thereafter, the repetitive works, which is education buildings project network was developed by logically inter-connecting the networks of each school that are listed in the order of construction priorities. The network comprising these four typical school buildings is summarised in **Exhibit 5.5**.

5.3.2 Education Buildings Phase I

As already covered under work scope of 2000 Housing Units Project in **Chapter 3**, the project consists of 15 Educational Modular Buildings. These further comprise 5 Primary Schools, 4 High Schools, 4 Kindergarten, and 2 Nursery Schools. In the first phase of construction, the project stipulated construction of one education building of each type at specified locations. The construction activities of these buildings in first phase are tabulated in **Exhibit 3.7**. The precedence network of the group of these education buildings is drawn in **Exhibit 5.5**.

5.3.3 Raw Water Clarifier Construction Project

The civil works in a raw-water treatment plant of a refinery project includes construction of a clarifier, mixer chamber, sludge transfer basin, and foundations to support pipes and pump. Since the commissioning of the refinery depends upon the clarified water supply from the raw-water treatment plant, this work was accorded highest priority and a time limit of seven months, commencing from February 1, 1986, which was fixed for the completion of all civil works (**Exhibit 5.6**).

The clarifier RCC tank had an outer diameter of 22.0 m. It had both, an underground chamber and an above-ground level that is a 4.5 m high structure. The underground chamber had conical

Figure 5.5

Primary School Construction: Flow Diagram
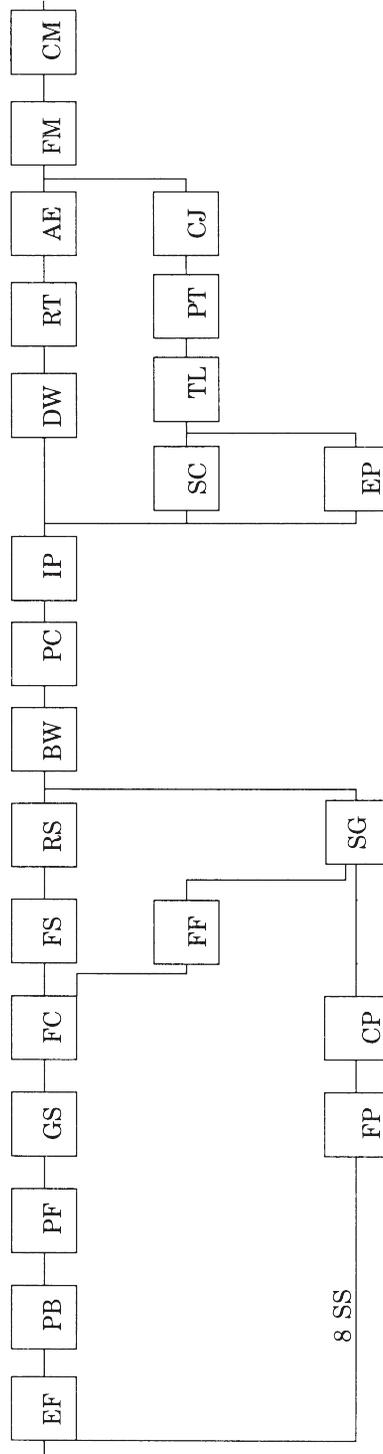
Logic Diagram of Foundation   Logic Diagram of Frame Structure   Logic Diagram of Block Work and Finishes

Exhibit 5.3

Primary School Structure Construction Precedence Network

| | Col & P | | | | FF | FF | Roof | |
| Exc & Ftg | Beams | Plinth Fig | Gd Slab | Column | Slab-1 | Slab-1 | Slab-1 | Blockwork |

0	3	3	6	6	8	8	11	11	13	13	16	16	20	20	23
EF	3	PB	3	PF	2	GS	3	FC	2	FS	3	RS	4	BW	3
0	3	3	6	6	8	8	11	11	13	13	16	16	20	20	23

FF
Slab-1

13	15
FF	2
18	20

Fdn Portals		Const Portal		Slab Gyn	
8	11	11	15	15	19
FP	3	CP	4	SG	4
9	12	12	16	16	20

8 SS
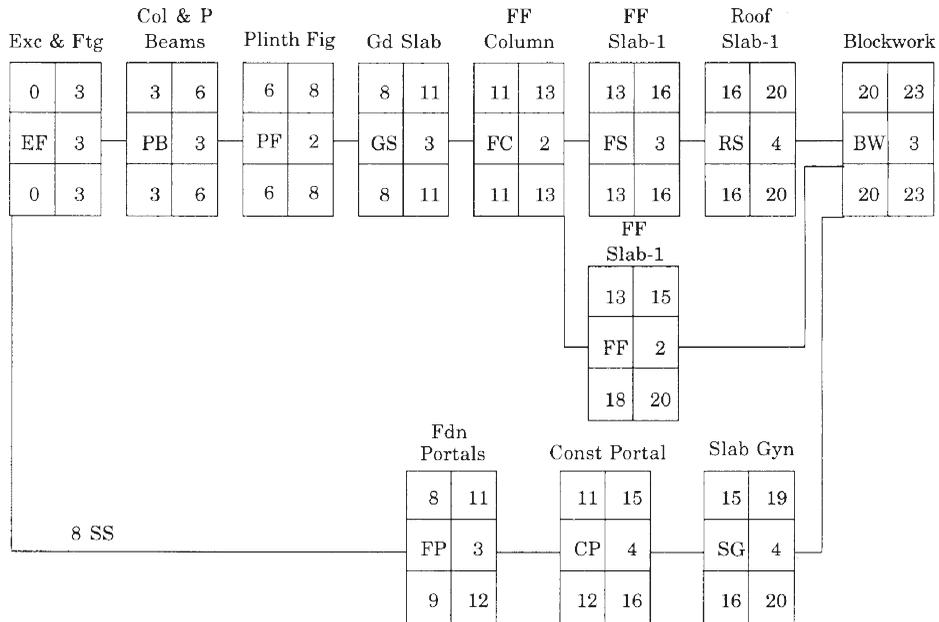
and trapezoidal RCC sumps. The heavily reinforced floor slab of the main tank acts as the roof for the underground chamber.

The main clarifier tank had an inner chamber of 7 m diameter that is constructed over the RCC columns. The inner chamber was encircled by twin circular RCC baffle walls. These circular twin narrow-spaced baffle walls had a semi-circular raised spillway at the bottom.

The outer ring wall was 4.5 m high above the RCC circular floor and the floor was supported on a circular base-wall of 1.8 m in height. The outer ring wall (dia. 22 m) had an overflow channel, which was to be cast along with the outer ring wall.

Construction sequence. The various stages in the construction of clarifier tank are:

- Construction raft of underground chamber;
- Building the perimeter wall of underground chamber up to conical sump;
- Elevating central circular areas of inner conical chamber up to the bottom level ground slab;
- Building baffle wall in three stages, namely, base, spillway inner wall and outer wall columns, and the outer wall;
- Raising the outer ring wall up to the bottom level of ground floor slab, followed by filling with lean concrete, except for two sectors on the opposite face to the entrance of underground chamber;
- This gap is left that provides an approach for concreting the remaining structure using 22 m boom-length concrete pump;

Exhibit 5.4

Summary Precedence Network of Primary School

* Foundation Wings 1 & 2		
0	11	11
0	FW	11

(−1 FS)

* Structures Wings 1 & 2		
10	11	21
10	SW	21

2FS

* Blockwork & Int. Plaster		
23	8	31
23	BP	31

* External Plaster		
31	2	33
3	EP	39

8 SS   − 1FF

Foundation Portals		
8	3	11
9	FP	12

Structure Gymnasium		
11	8	20
12	SG	20

* Ducting & Wiring		
31	2	33
31	DW	33

Roof Treatment		
33	2	35
39	RT	41

* Tiling & P. Painting		
33	6	39
33	TP	39

AC Equipment		
35	2	37
41	AE	43

* Carpentry & Joinery		
39	4	43
39	CJ	43

* Painting, Fittings & Eins.		
43	8	51
43	PF	51

* Critical Activity

- Filling the below ground area, enclosed by ring wall, with lean concrete for laying the central ground floor slab except the two approach sectors;
- Concreting the ground floor slab over the central circular area including slab of the underground chamber, baffle wall (dia. 7 m), both the sumps;
- Laying the remaining ground floor slab, sector-wise, with 10 cm kickers of outer ring wall (internal dia. 22 m) except the two approach sectors;
- Building the inner chamber in two stages, namely, column and ring beam, followed by cylindrical wall with slab;

Exhibit 5.5

Summary Precedence Network of Educational Buildings

Column headings (top, left to right):
FDN. 1 &2 FDN. PKTL STR. GYMM STR.W. 1&2 L.P. & PLTR DUCT & WRG EXT. PLTR ROOF PLTR TILE & PAINT AC EQPT CRP. & JNRY PAINT & FTC

Row labels (left): Primary School, High School, K.G. School, Nursery School
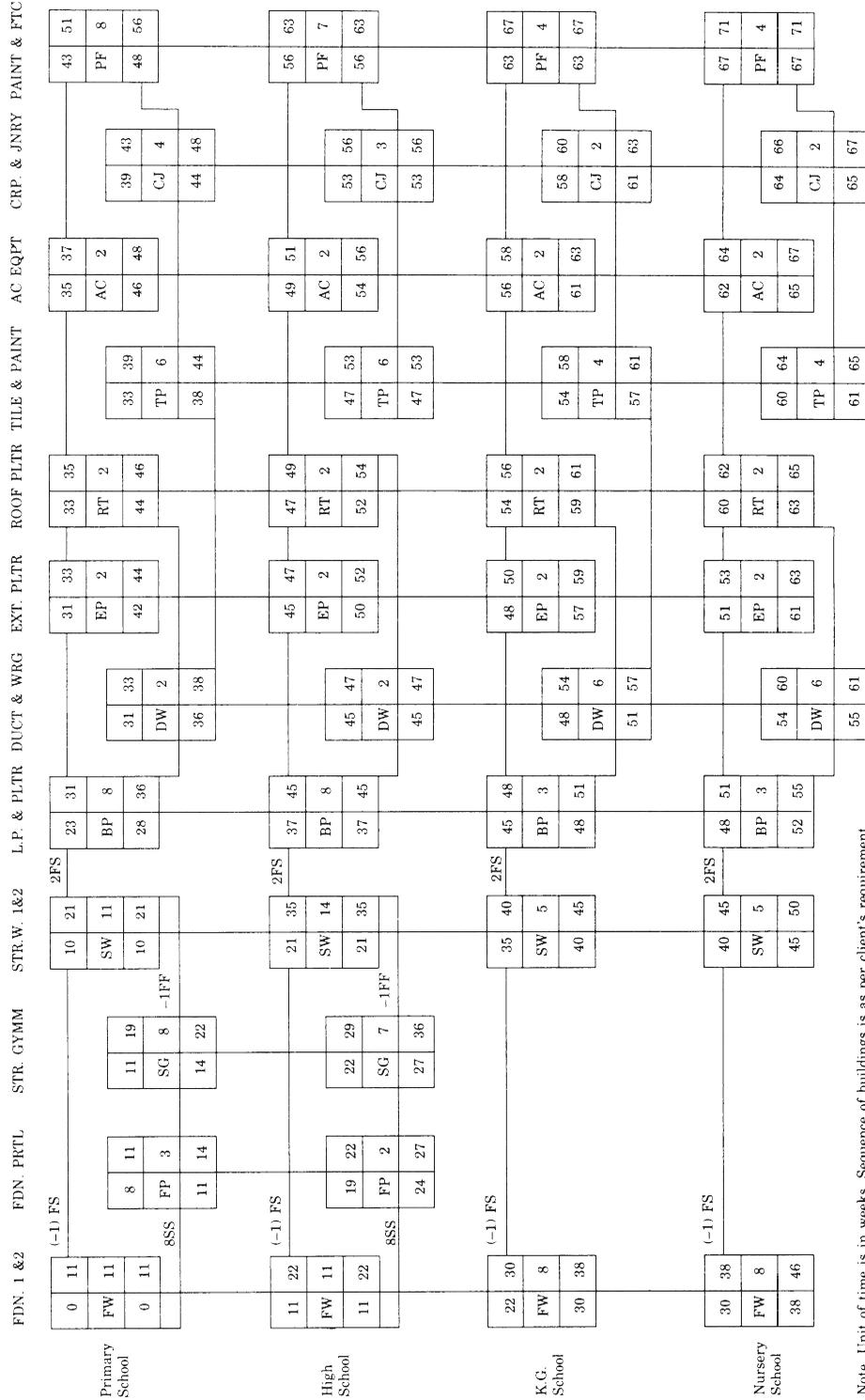
Note. Unit of time is in weeks. Sequence of buildings is as per client's requirement.

Exhibit 5.6

Raw Water Treatment Clarifier
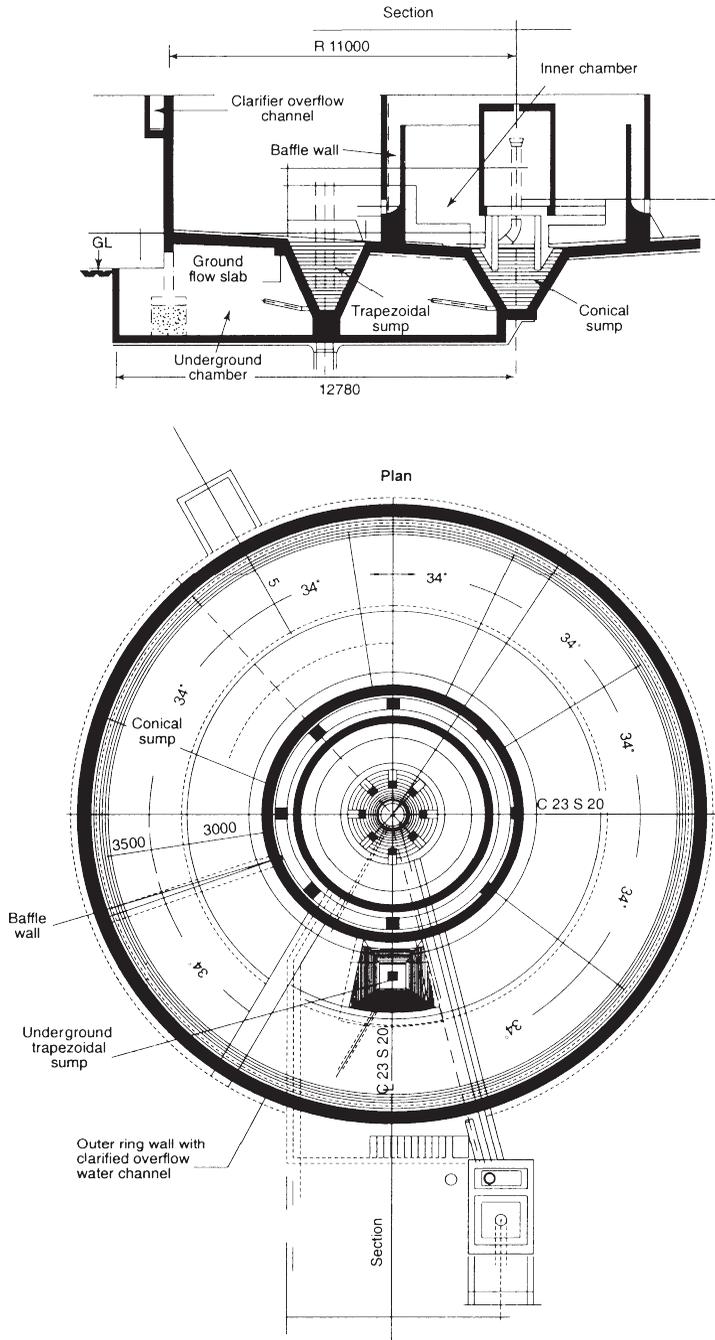
- Raising the ring wall (internal dia. 22 m), sector by sector, above the central ground floor slab, except for the two approach sectors;
- Constructing the remaining two sectors of outer ring wall; and
- Screening after installation of mechanical equipment.

Work breakdown. The construction of the water clarifier tank involves the following work packages. These along with their respective activities are shown in **Table 5.4**.

Table 5.4

Construction of the Water Clarifier Tank's Work Packages and Their Activities

S. No.	Work Package	Activities
1	Field location	Survey and layout.
2	Underground chamber	Excavation, blinding, raft concreting, wall concreting, and central ground floor slab.
3	Inner conical sump	Excavation, blinding, columns and beams, central ground floor slab, above-ground level wall and slab.
4	Baffle Wall	Excavation, blinding, base, wall, and central roof slab
5	Outer ring wall	Excavation, blinding, below-ground level wall (in three lifts), central ground floor slab, and level above-ground and outer ring wall (10 sectors).

Time analysed PN. The network of a raw water clarifier is shown in **Exhibit 5.7**. The completion time of civil works was fixed as 140 working days corresponding to the scheduled start date of February 1, 1986 and the completion date of July 12, 1986.The contractor planned for completing work in 120 fair-weather working days, earmarking the remaining 20 days as his reserve for rains and bad weather. The contractor's work programme, based on the earliest start time, is also given in **Exhibit 5.7**.

❑ 5.4 CLASSIFICATION OF NETWORKS

From the functional angle, the networks in a project are classified into four categories: skeleton network, master network, detailed network, and summary network. The purpose of these networks, the level of activity used the unit adopted for estimation of duration, and the rough cost of each activity is given below.

5.4.1 Skeleton Network

The project skeleton network depicts the preliminary or outline plan of the project using (subprojects and tasks) level of activities. The duration of each activity is estimated in months or weeks.

Exhibit 5.7

Raw Water Clarifier Tank Construction Precedence Network and Schedule

Template legend

EST	NO	EFT
AST	DOR	AFT

Activity Description

Underground Chamber

Mobilization & Survey

0	1	3
	3	

−1

Layout

2	2	5
	3	

Excavation

4	3	7
	3	

Blinding

8	4	9
	1	

Formwork & Rein Raft

9	5	15
	6	

+ 1 Day

Concreting

16	6	17
	1	

Formwork & Rein Walls 132M²

18	7	29
	11	

Inner Chamber

Formwork & Rein Column & Ring Beam

50	12	53
	3	

+ 1 Day

Concreting

54	13	35
	1	

Formwork & Rein Walls & Slab

56	14	61
	5	

+ 2 Day

Baffle Wall

Formwork & Rein First Lift

63	16	72
	9	

+ 1 Day

Concreting

73	17	74
	1	

Formwork & Rein Second Lift

75	18	84
	9	

Outer Ring West Wall

Excavation West Wall

15	22	18
	3	

+ 1 Day

Blinding

19	28	20
	1	

Formwork & Rein Footing

20	24	26
	6	

+ 1 Day

Concreting

27	25	28
	1	

Formwork & Rein Wall Below Gr. Slab

29	26	38
	9	

Rafs 22 / 10 Day

Outer Ring East Wall

Excavation East Wall

28	32	31
	3	

+ 1 Day

Blinding

32	33	33
	1	

Formwork & Rein Footing

33	34	39
	6	

+ 1 Day

Concreting

40	35	41
	1	

Formwork & Rein Wall Below Gr. Slab

42	36	51
	9	

+ 2D

Outer Ring North Wall

Excavation North Wall

95	42	97
	2	

+ 1 Day

Blinding

98	43	99
	1	

Formwork & Rein Footing

99	44	101
	2	

+ 1 Day

Concreting

102	45	103
	1	

Formwork & Rein Wall Below Gr. Slab

104	46	106
	2	

Baffle Wall Completion

Completion

The rough cost of each activity varies from 0.5% to 5% of the project cost. Skeleton networks are prepared during the feasibility or engineering stage with a view to provide direction to the project management team.

5.4.2 Master Network

This network is designed for controlling the systematic execution of a project or contract. It generally uses work packages as database. Its unit of time for duration estimation is considered in weeks. The rough cost of each activity is 0.1%–2.5% of the project cost.

5.4.3 Detailed Network

This network is prepared for the execution of day-to-day work, conforming to the sequence of activities given in the master network. It contains lower-level activities, whose duration is assessed in terms of days. These are prepared for controlling the extremely important sub-projects, tasks or contracts where the progress of work is to be watched and controlled on a day-to-day basis. Detailed networks are also prepared for determining the duration of a work package.

5.4.4 Summary Network

This network depicts the summary of a master network. In the summary network, sub-projector task level is used and their duration is assessed in weeks. The project summary network and its schedule are used in project information reporting to the top management. One of the methods of summarising a master network is to introduce the hammock activities to link a sub-network or a group of activities, as explained earlier.

❑ 5.5 GUIDELINES FOR DRAWING PROJECT PRECEDENCE NETWORK

The networks drawn using standard conventions are easily readable and acceptable. These rules for drawing networks depend upon the network technique employed. The rules for drawing the CPM/PERT sub-networks are covered in **Chapter 4**. The PN drawing conventions are described herewith to standardise details presentation.

5.5.1 Network Purpose

A project needs different types of networks like master network, summary network, and contract control network, at various levels of control. The first step in drawing a network is to decide upon the type of network required and then drawing separate networks, which incorporates relevant information for each level of control. Initially, the draft of the network should be prepared in pencil and should be discussed at various levels. As far as possible, the level of activities within a network should be kept consistent.

5.5.2   Network Drawing Sheet Size

Each type of network should be drawn on convenient size sheet not exceeding A0 size (1189 mm × 841 mm). An A0 size drawing sheet is sufficient for as many as 200 activities. Networks should be split into various sub-networks linked by the interfacing activities or events (shown in boxes or circles) and should be drawn on smaller size (A3 or A4) paper.

5.5.3   Project Network Layout Stratification

Prior to the commencement of integration, the paper on which the project network diagram is to be drawn should be divided into various strata. Stratification means division of the network diagram in such a way that activities pertaining to the same department, contract, location, or method of construction, can be grouped by drawing horizontal and/or vertical lines. Generally, the strata can be visualised from a prior knowledge of work scope in a project. These can also be easily deduced from the Work Breakdown Structure. The method of stratification is covered in **Chapter 4**.

5.5.4   Network Layout

The on-repetitive networks should be developed horizontally, starting from left to right. The path containing the maximum activities should be positioned in the middle portion of the network, while the remaining activities should be suitably positioned on its upper and lower sides. For repetitive work networks, the linking of activities should be horizontal or vertical, according to the requirement.

Check that all activities are included in the network. The standard network symbols and method of linking symbols should be used. The non-standard symbols if used should be clarified.

5.5.5   Network Logic

The following guidelines may reduce complications arising from the multiple nature of dependency logic:

1. Outgoing dependency lines can be drawn on the activity box, either from left top or bottom, or from the right edge of the activity box. For repetitive work projects, the middle of bottom side may be used to link up repetitive activities vertically.
2. Activities heading to an activity box, depending upon logic, are mostly linked with the left edge of the activity box. In rare cases, the right edge or top side of the box is used to represent the start-to-finish and finish-to-finish logic.
3. Crossing and/or reversing of dependency lines should be minimised by suitably positioning the activities.
4. Arrowheads should be drawn wherever necessary to clarify the direction flow.

It may be noted that in case of logic constraints:

1. There can be more than one different type of relationships between any two given activities.
2. The situational time constraints can be positive or negative in order to show overlapping or separation of activities. For example, a succeeding activity completion constraint imposed on the completion of preceding activity, can have a negative delay effect.
3. Too many relationships can complicate a network. It can also result in conservative estimates as there is a tendency to use extensive overlapping while attempting to meet a predetermined objective.
4. Unless absolutely essential, it is a general practice to restrict the situational constraints to a minimum. It can be done by restructuring logic in such a way that the succeeding activity starts only after the preceding activity(ies) has been completed, even if this amounts to a further splitting of related activities.

5.5.6   Events and Dummy Activities

Generally, PNs do not have events and dummy activities. However, there are few exceptions. Where PN starts (or ends) with more than one activity, its start (or end) can be shown by a start event (or an end event). In large networks, connectors are used to separate part of a network for providing logical links. In addition, interface in the form of dummy event can be introduced to mark the overlapping of sub-networks. The connectors and dummy events are shown in **Figure 5.6**.

❏ 5.6   PNA VS. CPM

5.6.1   Same Family

Both Critical Path Method (CPM) and Precedence Network Analysis (PNA) belong to the family of network analysis techniques. The common features, as already mentioned in **Chapter 4**:

- Make use of the network-type graphic model to depict the time plan for project execution ;
- Apply the critical path analysis concept for determining project duration and identifying critical activities; and
- Employ these network analysis techniques for scheduling and controlling of projects.

Although CPM and PNA network models may appear different; however, they are logically are similar. For a given project, both CPM and PNA network contain same job activities and durations. In case of networks, using finish-to-start logic, activity times and extent of floats are equal. This can easily be seen from the CPM and PNA networks of the Pumping Station Project shown in **Exhibit 5.8**. Generally, a CPM network can be converted into a PNA network by the following steps:

1. Delete dummy activities and isolated start and end events.
2. Identify preceding events of all the non-dummy activities.
3. Draw boxes around the non-dummy activities to enclose the preceding event, activity description and its duration.

Figure 5.6

**Dummy Events and Connectors to Link
Precedence Activities/Sub-networks**

(a) Use of dummy connector to link multiple activities, where logic permits so as to avoid congestion. Dummy events can be drawn as boxes or circles.
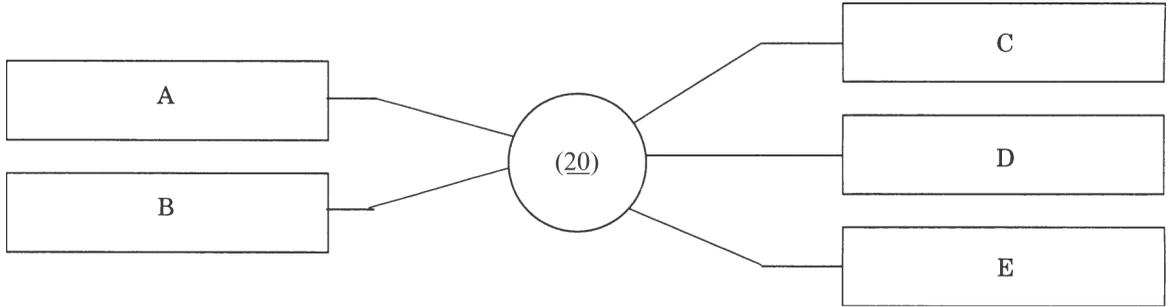
(b) Use of connectors to separate parts of networks.
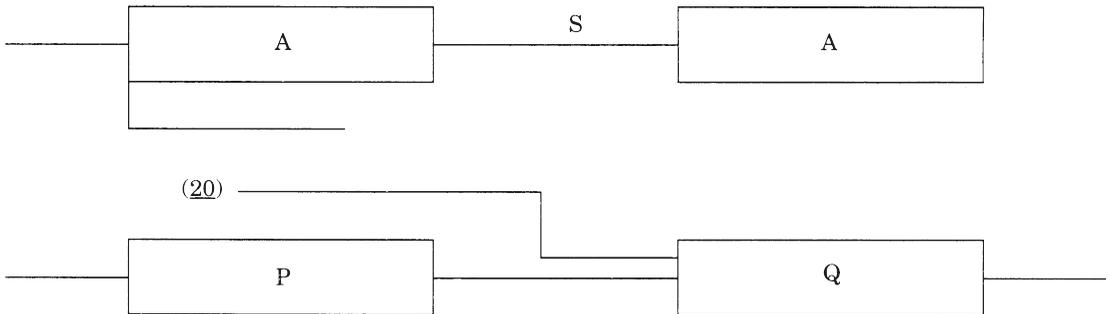
4. Develop PN by linking activity boxes with dependency lines using the finish-to-start relationship.

Both PNA and CPM are used extensively for planning construction projects. They have some common features as well as significant differences.

5.6.2 Common Features

- Both separate planning and scheduling. In network-based project, network planning precedes scheduling of work and budgeting of resources.
- Both enable systematic and logical development of time programme of complex projects with resource constraints. In these programmes, the scope of work and inter-connection between activities get clearly defined.

Exhibit 5.8

Site Development Project CPM and PNA Networks

Top diagram (CPM network):

Site A — 9

Site B — 2 → node (1 | 2 / 9)

Site G — 4 → node (3 | 6 / 13)

Site L — 7

Node (0 | 0 / 0)

Site C — 3 → node (2 | 3 / 3)

Site H — 17 → node (7 | 20 / 20)

Site D — 5 → node (5 | 5 / 16)

Site I — 4

Site E — 4 → node (4 | 4 / 12)

Site J — 8

Site F — 3 → node (6 | 4 / 14)

Site K — 6

Bottom diagram (PNA network):

A		
0	9	9
11	1	20

B		
0	2	2
7	7	2

G		
2	4	6
9	3	13

A		
6	7	13
13	5	20

START
0
0

C		
0	3	3
0	4	3

H		
3	17	20
3	6	20

END
0
13

D		
0	5	5
11	7	16

I		
5	4	9
16	9	20

E		
0	4	4
8	8	12

J		
4	8	12
12	10	20

F		
0	3	3
11	11	14

K		
4	6	10
14	12	20
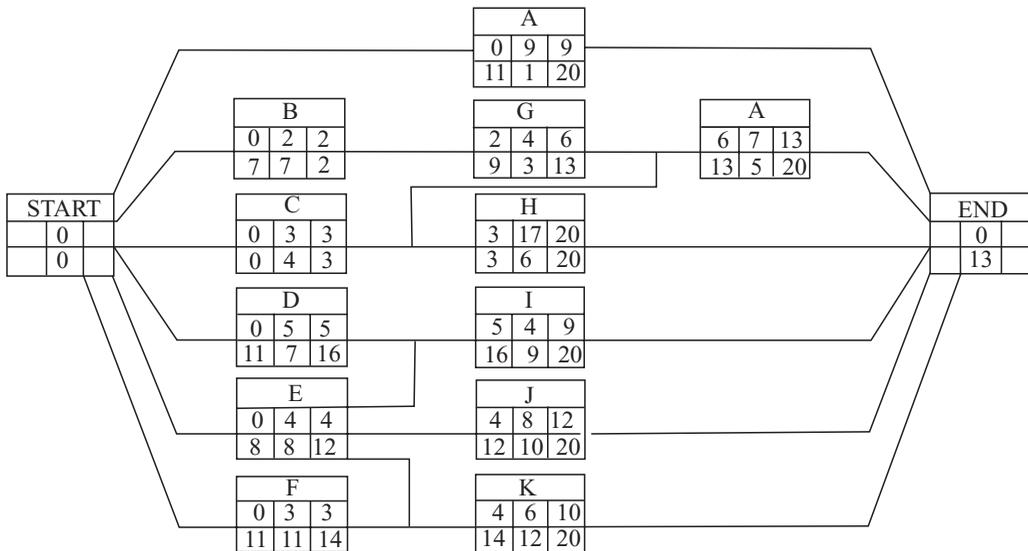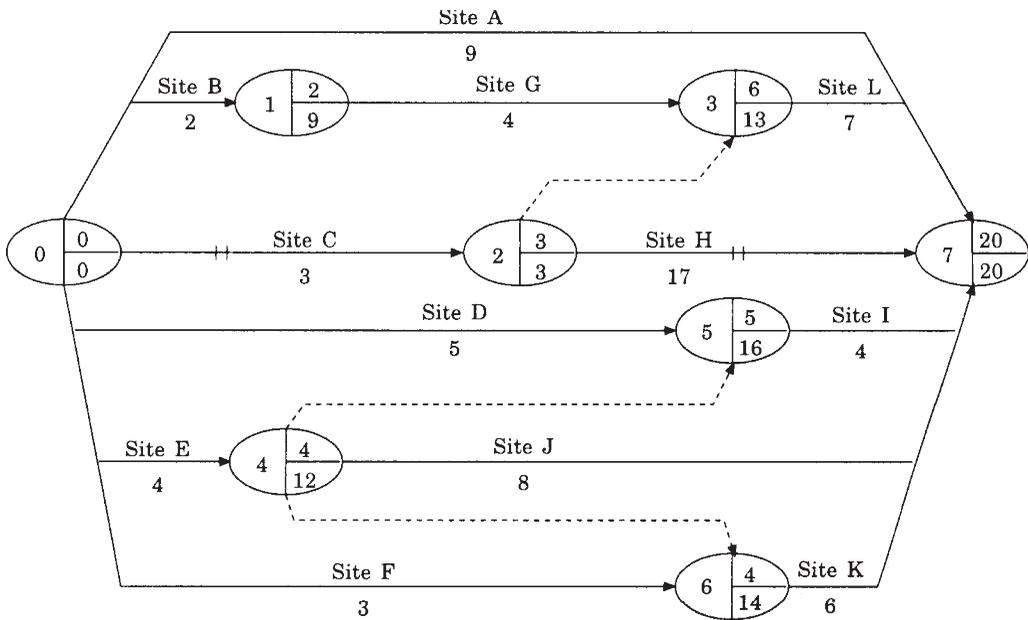
- Both depict inter-dependence diagrammatically. This eases comprehension of the tasks involved, anticipation of potential problem areas, and judging the implication of changes.
- Both help in establishing a relationship between time and cost, thus enabling optimisation of resources.

- Both are independent of time axis and, therefore, do not become outdated with the passage of time.
- Both aid in establishing key events, scheduling of work, budgeting of resources, and measuring of risks on a scientific basis.
- Both provide basis for monitoring progress and analysing effect of deviations.
- Both help in exercising management-by-exception, by focusing thought of the management on critical activities.
- Both provide the common language for communication among all those connected with management of projects, thus, reducing communication gaps, coordination effort, and contractual disputes.

5.6.3   Major Differences

Comprehensive appearance.   The PNA presents a better appearance than CPM. In PNA, activities are generally arranged in rows of symmetrically placed horizontal boxes connected with dependency lines, whereas, CPM contains arrows, dummy arrows, and events drawn in forward direction at various angles.

PNA is simpler.   It does not contain dummies, events, or unnecessary low order activities. This reduces chances of error, size of network, and the data processing effort. Colour code, if used for activity boxes in PNA, enables easy identification of critical and non- critical activities. Different colour codes on these activity templates can also represent responsibilities and resources. In PNA, each activity box includes relevant data for time and resources that are needed for analysis; but in CPM it is distributed on arrows and connecting events.

Ease of drawing.   The logic-arrow diagram of CPM is easy to draw, whereas, PNA takes more time to develop its logic sketch. After finalisation of logic diagram, PNA is quicker to draw than CPM.

Realistic logic representation.   PNA takes into consideration overlapping of activities. These overlapped activities present a realistic sequence of engineering tasks as they occur in actual execution. PNA can represent four types of logic, namely, finish-to-start, start-to-start, start-to-finish and finish-to-finish. These cover real life situations better than the CPM's single finish-to-start relationship approach.
Ease of logic alteration PNA enables easy alteration as it involves connecting dependency lines instead of shifting of arrows and events as in the CPM network.

Ease of understanding and communication.   The CPM network with its distinct events and simple logic relationship can be easily understood by those not familiar with network analysis. This is difficult in case of PNA having multiple logic relationship. Computerisation of network CPM, having single logic relationship of finish-to-start generally needs less input data than PNA with its multi-logic approach. However, for a network of the same project, PNA has less activity input as there are no dummies.

PNA networks can be zoomed in various sizes and levels on computer screen according to the information needs of various management levels. The detailed activity networks can be easily transformed to the summarised versions. Manual analysis of network CPM is comparatively easier to analyse than PNA. In case of PNA, all the time data has to be transferred from one activity to its adjoining activity, before analysing the adjoining activity.

In PNA, each activity is given a unique label number. This label can also be used to indicate the activity resources; whereas, in CPM, the activity label changes with alteration of logic or addition of new activities.

Time scale network schedule.   The schedule derived from CPM can be drawn both in bar charts as well as the 'time scale network' format where each activity is drawn to time scale. The 'time scale network' linked schedule is difficult (but possible) in PNA.

5.6.4   Network Analysis Application

Networks are the tools employed by planners for planning and controlling the project time objectives. These are instruments representing the mutually agreed plan of action between client and the project executing agencies. Although their preparation, monitoring, and revision is generally confined within the planning department, they form the basis for discussion and communication of information among the project management team and with the client.

Network-analysis is the most useful technique developed to help the project management perform its functions efficiently. Experience shows that in complex construction projects:

1. The CPM is best suited for developing sub-project, task or workpackage, sub-networks having activities with deterministic single-time duration.
2. The PN is better suited for time planning of construction projects.
3. Network containing up to 300 activities or workpackages are manageable, while, those above this are difficult to comprehend. Generally, the large-sized projects employing PNA technique use the following levels of details:

Network Classification	Level of Details
Project summary networks	Sub-projects or tasks
Project master networks	Work packages
Contracted works networks	Activities

5.6.5   Limitations of Network Techniques

1. Though, simple and straightforward, the introduction of network analysis requires specialised training.
2. Network analysis is not very useful for planning repetitive type of work. The planning of such projects needs scheduling rather than preparation of a ladder-type network. However, an

integrated use of project network and line-of-balance technique (see **Chapter 6**) can be use-fully adopted for repetitive projects.

3. Network analysis provides the means for making decisions, but the actual decisions have to be made by the management itself. It is not a substitute for bad management.

4. Network analysis indicates practical courses of action to accomplish specified time objec-tives. A project network shows the sequence and inter-dependence of activities. A network is scheduled to determine the commencement and termination date of each activity for ac-complishing the task within stipulated time by using the optimum level of resources. It is the schedule, which outlines a plan for execution of work and not the network itself.

APPENDIX E

Decision Network and Tree Analysis

❑ E.1   INTRODUCTION AND SCOPE

In a system, the decision implies a commitment to an action. Decision making process involves; defining the objective, formulating the alternate courses of action, developing the model, evaluat-ing the alternatives, and finally selecting the best course of action for implementation. Decision network is a graphical model of decision environment that structures alternate strategic options or courses of action. The decision network is analysed to determine the optimal strategy or course of action that best achieves the defined objective. Decision trees refer to networks having probabilistic links.

The spheres of the Decision Network and Tree Analysis techniques in project management are vast and varied. It includes decision relating to market strategy, investments, project selection, production planning, manpower planning, material procurement, inventory planning, vehicles and plant forecasting, equipment replacement, and investment appraisals. Some of these applications are illustrated with simple examples in the subsequent sections.

The text in this Appendix covers deterministic and probabilistic decision network analysis, and, probabilistic decision trees analysis.

❑ E.2   TYPES OF DECISION NETWORK ANALYSIS TECHNIQUES

Decision Network is a generic term. The situation under which the sequential decisions are mod-eled may present information, which is either deterministic or probabilistic.
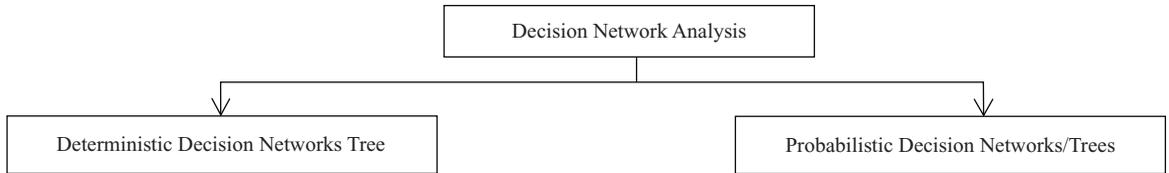
Both the deterministic decision network analysis and probabilistic decision tree analysis techniques aim at determining the optimal course of action but represent different situations and have different models.

Deterministic decision networks represent deterministic situations where a decision maker makes the decision under assumed certainty. These networks have a deterministic action plan where a decision maker can determine the outcome of his actions. The deterministic decision network technique is preferred for real life problems.

In probabilistic networks, the choice of action plan is influenced by the expected values, which are determined by summing up of the products of expected outcome (or payoff) with the probability of occurrence of the outcome. In fact, a decision tree is a particular case in which the network takes the shape of a tree with branches.

❑ E.3   DETERMINISTIC DECISION NETWORK ANALYSIS

E.3.1   Elements of a Decision Network

A decision network consists of circles that symbolise the events or the changing states of the system, and arrows denoting the course of action by which these states are affected (see **Figure E.1**). The numerical value of the outcome of an action, termed return, is written above the action arrow. A stage represents the transition interval between the present and the adjoining state. In decision networks, it is assumed that the adjacent state is independent of how the preceding state was reached (see **Table E.1**).

Figure E.1

Stage of a Decision Network
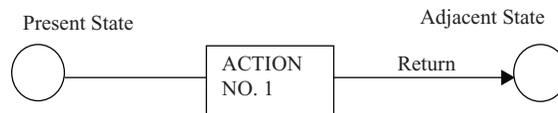
Figure showing the stage of a Decision Network

Elements of a Decision Network include state of the system, course of action, return and stage. These are shown in **Table E.1**.

The chains of action, in a decision network are connected logically with the states and these states in turn are correlated to the stages of their occurrence. These occurring stages are depicted

Elements of a Decision Network

S. No.	Element	Representation	Symbol
1.	State of the system	Circle. The state is represented along or parallel to x-axis.	◯
2.	A course of action	Arrows in forward direction. Action numbers are written inside the rectangle.	No.
3.	Return	Return value shown at the arrow culminating in an adjacent state.	3 ➤◯
4.	Stage	Transition interval between the present and the adjoining state. It is generally represented along Y-axis.	
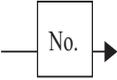
in relation to framework of vertical and horizontal axis, representing state levels and stages in the system respectively (see **Figure E.2**).

Figure E.2

Decision sub-network
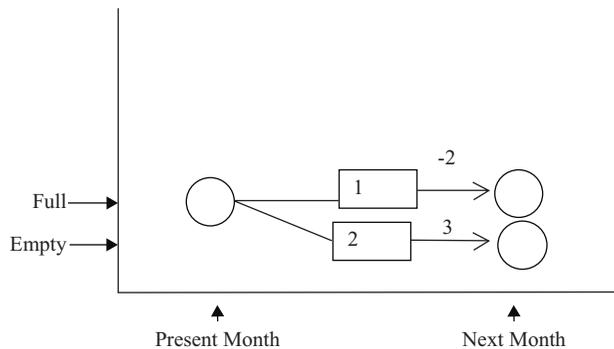
The above decision sub-network shows that in the present month, the warehouse is full. Thereafter two courses of actions are open. These are:

1. Course 1. Keep the warehouse full till next month and do not sell the stores. This will involve expenditure of 2 units.

2. Course 2. Sell the stores within this month. This course will result in a return of 3 units, but the warehouse will be empty next month.

Explanatory Notes on Elements of a Decision Network

Stage: It is the transitional phase or an interval that marks the movement of a system from one state to the adjacent state. For example, the time interval between the two states corresponds to a stage of the system. In decision network, stage is represented along the horizontal axis.

State/Situation: A state/situation depicts the nature at the start or termination of an action. The existing state, after an action, moves to the adjacent state, e.g. from a warehouse full with stores, if the stores are moved out after sale, it can be said that the sale of stores (an action) has resulted in changing the state of the warehouse from full to empty state. The state/situation is represented by a circle. In deterministic decision networks, the pattern of changing states of a system is always represented along the vertical axis.

Action: The action changes the state and is depicted by an arrow connecting the previous state with the adjacent state. A rectangle or a square is drawn close to the tail of the action arrow. Various courses of action are labelled numerically and each action number is written inside the action rectangle/square.

Return: The return represents the yield, such as profit, cost, consumption, or distance; resulting from a given action, which changes the state. The return in numerical value is written above the arrow/branch; in between action rectangle/square and the adjacent state circle.

Payoff: It denotes the benefit that accrues from a given combination of a decision alternate and the state of a system.

Optimal Decision: It implies selecting the most suitable chain of course of action that aids in achieving objectives. This chain, representing the course of action, is identified by analysing the decision networks, generally using the forward and/or backward pass method.

E.3.2 Deterministic Decision Network Modelling and Analysis Procedure

In deterministic decision networks, there are no probabilities assigned to the state of nature. In such cases, the decision maker operates under conditions of assumed certainty. The Network Modelling and Analysis procedure is as follows:

a. Define the objective of a decision process. It can be to maximise or minimise the effect of the decision. Example–maximise profits.
b. Develop the alternate courses of action.
c. Model the decision network (process) using standard symbols.

d.   Assign returns and investments to each of the branches, as applicable.

e.   Analyse the decision network by rolling backward or forward pass method to determine the optimal chain of courses of actions.

The above procedure is illustrated with examples of deterministic networks.

E.3.3   Example of maximising return in warehousing a product

The management is faced with a problem whether to keep a warehouse full or empty with a perishable product having two months life. In the present month, the warehouse is full. Thereafter following courses are open:

1.   *Action No.1*. Do not sell the stores now and sell them next month. This will involve expenditure of 1 unit but the sale in the beginning of next month is likely to give a return of 3 units.

2.   *Action No. 2*. Sell the stores within this month. This course will result in a return of 2 units, but the warehouse will have to remain empty thereafter.

3.   *Action No. 3*. Sell now from the full state and later (during this month) buy fresh stock to keep the warehouse full for the next month's sale. This course will result in a net return of 1 unit during the first month, but the sale in the beginning of next month is likely to give a return of 3 units.

Management has also decided to discontinue the trading of the present product and market another product after two months. The decision network of this simple problem is given **Figure E.3**. The analysis shows that the Action No. 3 followed by Action No. 1, is the most profitable option yielding a return of 4 Units. Note that all states and actions are labeled for reference purposes.

Figure E.3

Structured decision network
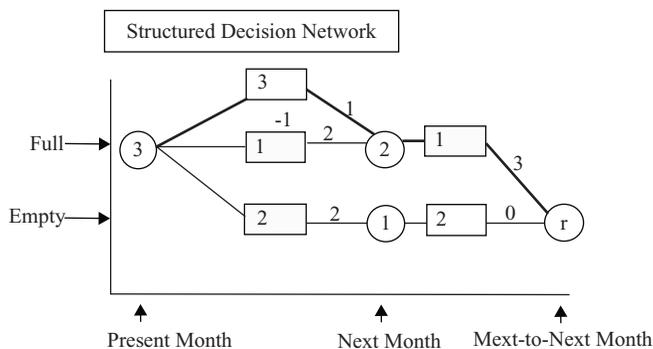
E.3.4   Example of Minimising Manpower Cost

A contracting company engaged in pipe laying in a refinery project needs high precision welders. The schedule requirement of the project is as under:

Month	Jan	Feb	Mar	Apr	May
Welders	5	6	7	8	6

The company has 5 regular welders. The management after due appraisal has evaluated the following information:-

a. The cost of inducting welders from outside to the worksite is SR. 1000 for one welder and SR. 1500 for two welders respectively. The transfer out of each welder from work site costs the company SR. 1000. It is not feasible to induct more than two welders at a time from the level existing on the previous month.
b. All transfers to the worksite generally take place on the last day of the previous month and the men are effective from the next day i.e. first day of the following month.
c. The cost of having a surplus precision welder on site is SR. 500/month as the spare precision welder can also be used for normal welding purposes.
d. Existing welders can be put in overtime but due to the precise nature of working overtime, it must not exceed the equivalent of one welder per month, i.e., SR. 1500/month.

The company wants to evaluate the induction plan in and transfer out plan of the work site, for mobilising and demobilising welders, which shall minimise the company's total cost but at the same time assure that the requirement of welders are met.

Solution

In the initial stages in January, five welders present at the site are adequate and hence no action is required to be taken during this month. Number of welders required from the start of February to May varies. There are a number of courses open for mobilisation of welders at various stages. These courses of action with implications are tabulated below:

Options

S. No.	Option Code	Course of Action	Expenses in SR
1.	N	No additional welder required	0
2.	O	Overtime work	1500
3.	A	Induct in one welder	1000
4.	B	Induct in two welders	1500
5.	C	Transfer out one welder	-1000
6.	D	Transfer out two welders	-2000

In the decision network, the varying manpower state is scaled along the vertical axis and the monthly stages are shown on the horizontal axis. The decision network for various courses of action that are involved in the mobilisation of manpower with the cost involved is shown in **Figure E4**; the shortest path is shown in bold lines and circles:

There are number of expenditure paths. These include 0-1-4-7-8; 0-2-4-7-8; 0-3-4-7-8; 0-2-6-7-8; 0-1-4-5-8. Since, the problem relates to minimising the cost, the shortest path of the decision

Figure E.4

Graphical Solution of Welders Mobilisation Problem
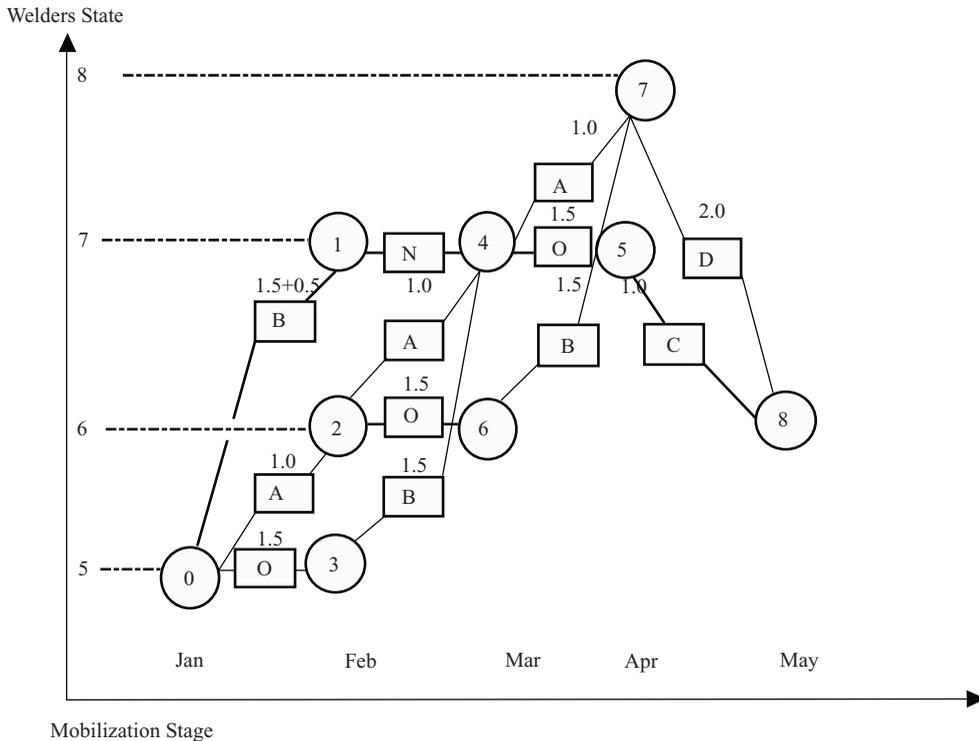
network calculated by forward or back-pass reveals a minimum mobilisation expenditure of SR. 4500/- for 0-1-4-5-8 (shown in bold lines and circles). Decision plan for minimising additional manpower mobilisation costs works out as given in **Table E.2**:

In particular, action 0–1 entails expenditure of SR. 1500, at start of February towards transportation of two welders. The decision models, where several outcomes with varying chances of occurrence, could possibly follow the selection of a particular course of action are referred to as probabilistic models. In such cases, the decision maker depending upon the extent of information available can assign the probabilities of occurrence to each possible outcome.

Salient Features of a Probabilistic Decision Network. In probabilistic decision network, each action has a number of transition probabilities associated with it. The method of representing actions, which takes into consideration transitional probabilities, is different from those of deterministic actions (see **Figure E.5**):

The salient features of a probabilistic decision network model are:

a. Return is written above the branch/arrow in between the action and the present state.
b. Each action has a probability of transition to other states associated with it. These probabilities have to be assessed by the decision maker.

Table E.2

Decision Plan for Minimising Additional Manpower Mobilisation Costs

S. No.	Month	Welders Reqt Min	Mob. Decision Options	Mob. Action Path	Mob Expenses	Min. Mob. Cost 0-1-4-5-8
1	1st January	5	Existing			
2	Feb. (End January Induction Option)	6	A . Induct 1 welder B. Induct 2 welders O.. Work overtime	B (0-1) A (0-2) O (0-3)	1500 + 500 1000 1500	1500 + 500
3.	Mar. (End February Induction Option)	7	N. No welder mob. A. Induct 1 welder B Induct 2 welders O. Work overtime	N(1-4) A (2-4) B (3-4) O (2-6)	0 1000 1500 1500	0
4	Apr. (End March Induction}	8	A. Induct 1 welder B Induct 2 welders O. Work overtime	A (4-7) O (4-5) B (6-7)	1500 1500 1500 1500	
5	May. (End April Demob)	6	C Transfer 1 welder D. Transfer 2 welder	C (5-8) D (7-8)	1000 2000	1000
	Minimum l tpn cost					4500

Figure E.5

Illustration Showing a Stage of a Probabilistic Decision Network
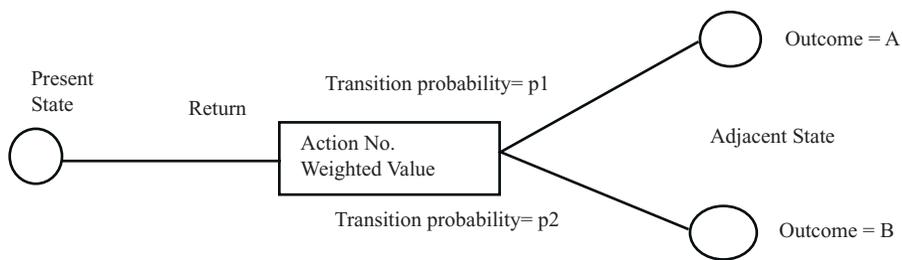
c. The lower portion of action rectangle is used for writing the weighted values of the adjacent states. For example, if A and B are the values of total returns at two adjacent states and p1 and p2 respectively are the transitional probabilities associated with these states resulting from a given action then

$$\text{Weighted total return or expected profit} = p_1 A + p_2 B$$

d. Action identification labels are written on the upper half of the action rectangle.
e. The sum of the transitional probabilities associated with an action is always equal to one.
f. A probabilistic network can contain both probabilistic as well as deterministic actions.

Example: Developing Market Strategy. Ready-mix concrete (RMC) is a pre-mixed quality-controlled concrete. The mix has designed proportions of concreting materials. It is delivered to construction sites for ready to use. An RMC plant has batching plant(s), transit mixers and storage bins for the aggregates and sand. The cement is stored in silos. For bag delivery cement, it has bag-cutting and cement-conveying equipment. Water is stored in tanks and is pumped in measured quantity to the mixer. In addition, an RMC plant usually has a laboratory and housing facility for the workers.

An RMC company is planning its market strategy for the next year. The planners, after carrying out an investment appraisal on alternative strategies, assessed the profitability for the company over the next 12 months as follows:

- *Option S1*: Installing new plant immediately can increase the profit by $1.0 m;
- *Option S2*: Adding new plant gradually can result in a profit of $0.6 m; and
- *Option S3*: Continuing business with present facilities can yield a profit of $0.4 m.

The above profitability, is based on the assumption that the market with its up-trend will grow by 20%. However, the possibility of market demand remaining stable or the falling market cannot be ruled out. The expected probabilities and profit by the experts are tabulated below:

Market Outcome	Probability
20% Rise	0.6
Stable	0.3
10 % Fall	0.1

Pay-Off Matrix

	Nature of Market with Probability of Growth		
Market trend Probability of change	20% rise 0.6	Stable 0.3	10% fall 0.1
Strategic Options		Expected Profitability	
S1: Expand immediately by inducting new plant	$1.0 m	$0.2 m	0
S2: Expand gradually	$0.6 m	$0.3 m	$0.1 m
S3 Maintain present capacity	$0.4 m	$0.3 m	$0.1 m

Solution:
The steps involved are:

- Step 1. Draw the network;
- Step 2. Calculate payoff for each strategy;
- Step 3. Select the strategy which yields maxi mum benefit;
- Step 4. Calculate the risk in payoff for each strategy; and
- Step5. Select the dominant strategy for making a decision.

Step 1. Draw the network. The market is expected to rise, but there is also a probability of it remaining stable or even falling out of demand. These trends can be represented along the vertical axis, while, the stage showing the change in the present state to the next year's situation can be represented along the horizontal axis. The network, thus developed, is shown **Figure E.6**:

Figure E.6
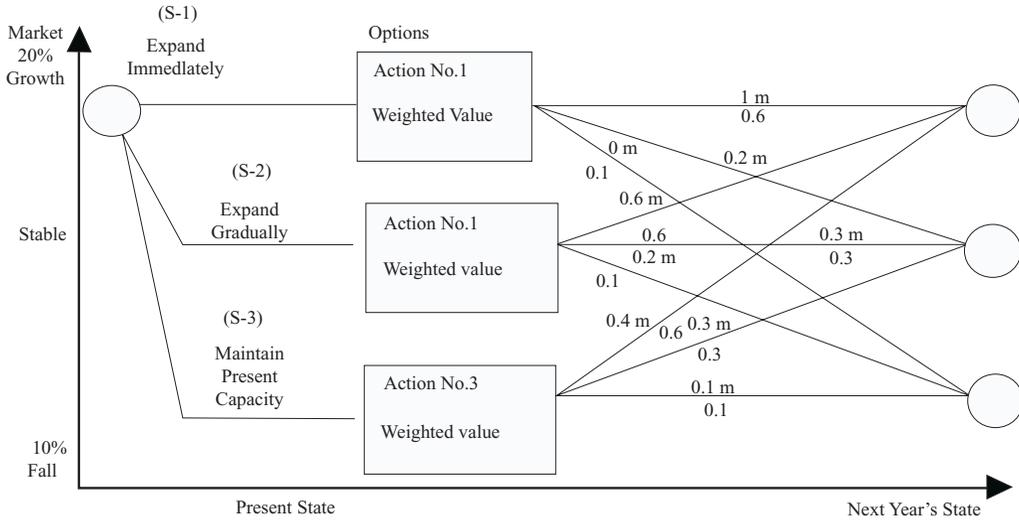
Step 2. Calculate expected outcome by multiplying the pay-off with probability for each strategy as follows:

Factor	Pay-Off	Probability	Expected Outcome
Growth	1.0 m×	0.6 =	0.60 m
Stable	0.2 m×	0.3 =	0.06 m
Fall	0m×	0.1 =	0 m
Total		=	0.66 m

Similarly, the expected profits of S2 and S3 can be worked out. These are tabulated below:

Payoffs in Expected Monitory Value (EMV) for Strategy S1, S2 and S3

Strategy	Description	EMV
S1	Expand immediately by inducting new plant	$0.66m
S2	Expand gradually	$0.46m
S3	Maintain present capacity	$0.34m

Step 3. Select the strategy which yields maximum benefit.   The pay-offs for various strategies reveal that S1, is the strategy that yields maximum expected profit. But the degree of risk in terms of variance and standard deviation for each action must be calculated before making a decision.

Step 4. Calculate the risk in payoff for each strategy.   The degree of risk is determined by calculating variance and standard deviation for each course of action. Variance and Standard Deviation for strategy S1:

Outcome	EMV	Deviation	D2 × Probability		Total
1.0	0.66	+0.34	0.1156 × 0.6	=	0.06936
0.2	0.66	−0.46	0.2116 × 0.3	=	0.06348
0	0.66	−0.66	0.4356 × 0.1	=	0.04356
Variance				=	0.1764
Standard deviation				=	0.42

Calculating similarly, the Coefficients of Variance and Standard Deviation are as under:

Strategy	EMV	Coefficient of Variation	Standard Deviation
S1	$0.66m	0.1764	0.42
S2	$0.46m	0.04	0.20
S3	$0.34m	0.0196	0.14

Step 5. Select the dominant strategy for making decisions.   Decision network supplies expected values for making decisions, but a decision based purely on expected monetary values is not enough. For example, in the Ready Mix Concrete problem solved above, each of the expected values has a certain degree of risks associated with it. The higher the expected value; the greater is the risk. It calls for the individual's ability to make a decision. Rules for making decisions are covered in **Appendix O**.

❑ E.4   DECISION TREE ANALYSIS

Decision network is a graphical method of analysing the outcome from a series of interdependent possible courses of action that are generated by the decision process. The decision tree is a special case of structured decision network, where the decision model is open-ended. In this model, decision points are represented by the squares, chance events, or the outcomes are denoted by circles and the branches indicate the courses of action and returns.

A decision tree for making Ready Mix Concrete marketing decision is given in **Figure E.7**. Other steps for making a decision are similar to the decision network given above.

Figure E.7
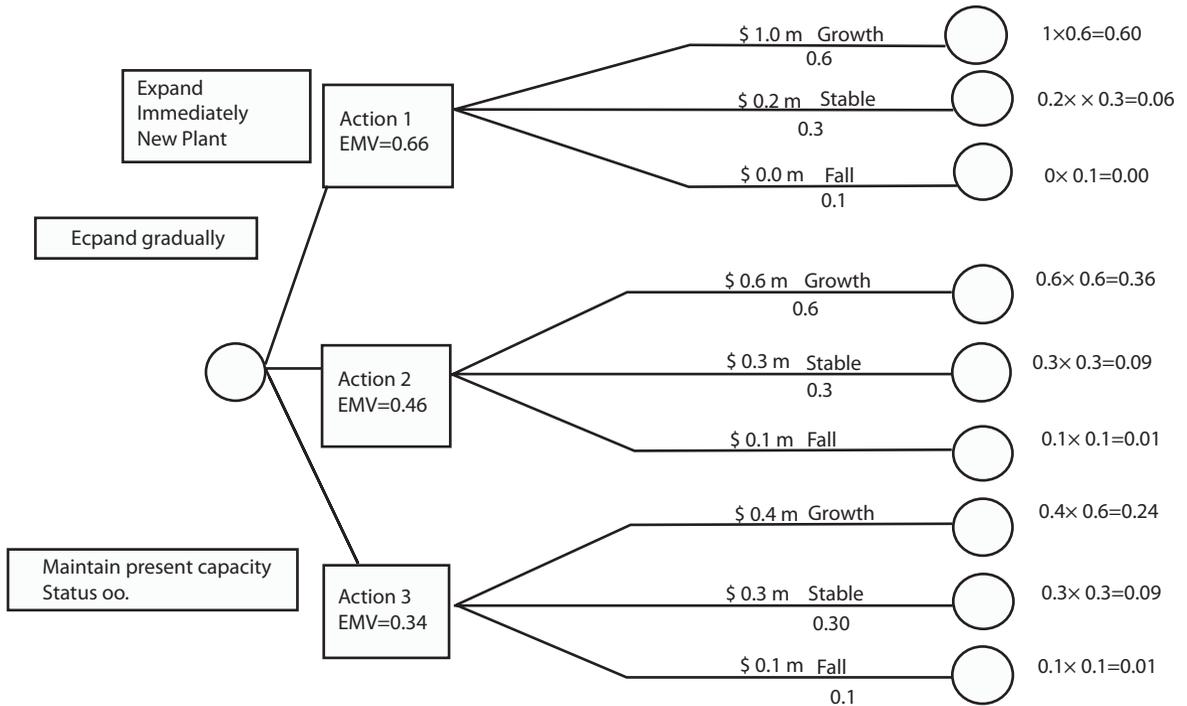
❑ E.5   CONCLUSION

A decision network and tree structures helps to solve a decision making problems in a systematic manner, examining all possible courses of action and the resulting outcome prior to making a decision. In particular, the decision network analysis technique provides a compact model to structure decision process; whereas, the decision tree is easy to develop but becomes cumbersome with the increase in number of sequential decisions. Decision network and tree structures provide approach for making a decision, but a decision based purely on expected values is not enough. The higher the expected value, the greater is the risk. It calls for the individual's ability to make a decision.

Scheduling Project Work and Resources

A *schedule* can be defined as a work programme that is set date-wise in a logical sequence. In other words, it can also be defined as a time table for action. Time scheduling is the process of developing a work programme. It implies programming of the chosen work plan on a calendar basis and provides the base against which time progress is measured. A work schedule is an action plan with calendar date targets, whereas, network is a planning technique. A network needs to be scheduled in order to determine commencement and termination dates of each activity, by using the optimum resources or working within resource constraints. **Exhibit 6.1** shows the schedule of a small-size Site Development Project employing the optimum level of critical resources (bull-dozers for earth-work). **Exhibit 2.1** depicts the bar chart programme of 2000 Housing Project. A project planning is not complete until all the activities are scheduled and forecast of major resources is developed.

The project employs resources of men, materials, machines, and money, in order to execute the activities. Time and resources to be employed in an activity are inter-related. In most of the construc tion activities, increase in vital resources from a certain level decreases duration of the activity. But this uneven employment of vital resource can reduce productivity, increase the cost, and create management problems. The aim should be to schedule the work in such a manner that vital resources are optimised.

The scheduling of resources in a project and multi-project environment is a complex process, but the focus should be to make it simple by scheduling a few vital resources and derive the forecast of the remaining resources. The project management software can aid in speedy development of network and project time schedule (see **Appendix F**).

The scheduling methodology varies with the nature of project, planning technique, and resources constraints. Simple projects can be scheduled using the 'bar chart methodology'. The Line-of-Balance (LOB) technique is widely accepted for scheduling the repetitive work projects; while, network scheduling is suitable for all types of projects.

Generally, all types of schedules use time scale along the horizontal axis. This time scale mostly uses 'day' as the unit of time; these days are then related to the calendar dates, weeks, and months.

Exhibit 6.1

Schedule of the Site Development Project

Working Period in Weeks

Activity	Dozer	Compressors	Duration
Task C	1	-	3
Task H	1	-	17
Task B	1	-	2
Task G	1	-	4
Task L	1	-	7
Task E	1	-	4
Task J	1	-	8
Task F	1	-	3
Task K	1	-	6
Task D	1	1	5
Task I	1	1	4
Task A	1	-	9

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Dozers Required	4	4	4	4	4	4	4	4	4	4	4	5	4	3	3	3	3	3	3	3

Each type of scheduling technique has its purpose, merits, and demerits. But ultimately schedules are best presented in the bar chart form for ease of comprehension and communication. These bar charts are supplemented with the appropriate planning technique for monitoring the progress of the projects. Time schedule monitoring techniques are covered in **Chapter 16**.

This chapter describes the work scheduling methodology into the following sections:

1. Work Scheduling Fundamentals
2. Bar Chart Method for Work Scheduling of Simple Projects
3. Network-Based Complex Project Scheduling Method
4. Line-of-Balance (LOB) Based Repetitive Projects Scheduling Techniques
5. Resources Scheduling Considerations
6. Schedule Hierarchy

Probabilistic Decision Network Analysis is covered in **Appendix F**. Critical Chain Method is explained in **Chapter 16**. Project networks can be easily developed using Project Management Software; this aspect is outlined with illustrations from Primavera software layouts in **Appendix F.**

❑ 6.1 WORK SCHEDULING FUNDAMENTALS

6.1.1 Object of Work Scheduling

Work scheduling serves the following purposes:

1. *It simplifies the project plan*. The bar-chart type work schedule provides a simplified version of the work plan, which can easily be understood by all concerned authorities or department with planning, coordination, execution, and control of the project.
2. *It validates the time objectives*. A work schedule shows the planned sequence of activitiesin date-wise manner. While, putting the work plan on a calendar basis, it takes into account reduced efficiency of resources to adverse climatic conditions and other factors. It also verifies the deadlines imposed for completion of the project and achievement of the milestones.
3. *It optimises the resources employed*. A work schedule is based on the most economical employment of the resources of men, materials, and machinery. It smoothens abrupt changes, which may occur from time to time. Resource optimisation is achieved by a systematic utilisation of the floats of non-critical activities. Unless otherwise constrained, a project is scheduled by using either the optimum or the available pattern of resources.
4. *It forecasts the input resources and predicts the output*. A work schedule enables the forecasting of resources and also indicates the pattern of resource consumption. The time schedule of work forms the basis for predicting the resource requirement as well as the financial state of the project in terms of investment, expenditure, output, income, and cash flow.
5. *It evaluates the implications of scheduling constraints*. A work schedule brings out the implications of constraints, and enables preparation of a work plan within the framework of these constraints.

6.1.2 Commonly Used Scheduling Techniques

The time scheduling methodology varies with the nature of projects. Simple projects can be scheduled using the 'bar chart methodology', whereas, complex projects need project network to prepare a schedule. The Line-of-Balance (LOB) technique is widely accepted for scheduling the repetitive work projects. Commonly used project management software are based on PNA. A tool kit containing the commonly used techniques for planning and scheduling are shown in **Table 6.1** below:

Table 6.1

Commonly Used Time Planning Techniques and Schedules Techniques

S. No.	Nature of Project	Planning Techniques	Schedule Displaying Techniques
1.	Simple projects (a) Non repetitive work (b) Repetitive works	Bar chart LOB	Bar chart LOB/Bar chart
2.	Sub projects (a) Deterministic (b) Probabilistic	CPM PERT	Bar chart Networks
3.	Complex projects (a) Non repetitive works (b) Repetitive works (c) Probabilistic	PNA PNA PERT	Bar chart and T S Networks LOB and Bar chart Networks

Abbreviations:

CPM: Critical Path Method.

PERT: Programme Evaluation and Review Technique.

PNA: Precedence Network Analysis.

LOB: Line of Balance Technique.

LPC: Linear Programme Chart.

TSN: Time Scale Network or Logic Bar Chart.

6.1.3 Schedules Classification

Broadly the work schedules can be categorised into Bar Chart Schedules, Network-Based Complex Projects Schedules and the LOB schedules for repetitive project. The types of schedules vary with the nature of project, time, and resource constraints. These are shown in **Figure 6.1**.

Example of network-based projects. Consider the Network of Site Development Project, it contains 12 activities, labeled A to L, whereeach activity requires one machine per day. The network depicting sequence and duration of these activities is given in **Exhibit 6.2**. Time and resource constraints in this work can result in varieties of schedules. These include the following and the methodology for their development is covered in later sections of this chapter.

Figure 6.1

TYPES OF
SCHEDULES

Simple Projects

Network-Based Complex
Projects

Repetitive Projects

Bar Chart Schedule

Line-Of-Balance
Schedule

Time Limited Schedules

Resources Limited
Schedule

Earliest Start Time
Schedule

Latest Start Time
Schedule

Optimum
Resources
Schedule
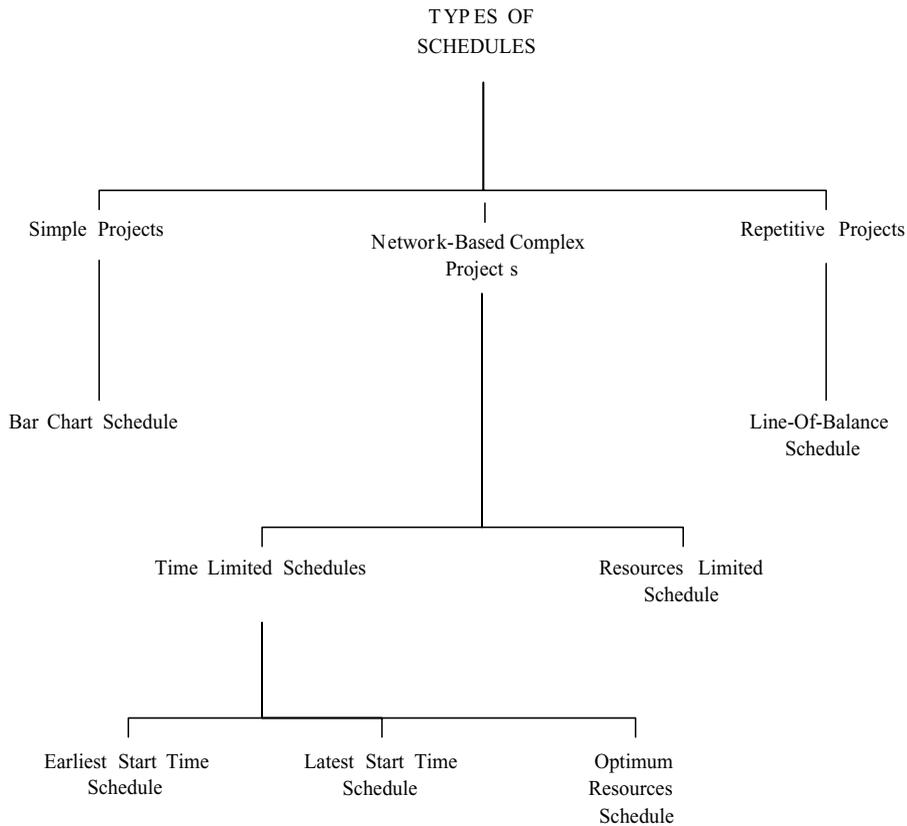
Earliest start time (EST) schedule. It is based on earliest start dates of activities as determined from network and shows daily requirement of machines, when all activities are scheduled according to their EST (see **Figure 6.2**).

Smoothened resources time schedule. It is based on employment of resources in a manner that smoothen requirement ofresources by evenly distributing their employment over a time period; and minimises peaks and valleys in the resources requirement profile.
Note: Resource optimisation implies scheduling of resources according to a given pattern of their availability (see **Figure 6.4**).

Resources limited schedule. It is based on availability of three dozers instead of four dozers that are needed for smoothening resources.
Note: In this case the time duration of the project has increased from 20 weeks to 24 weeks (see **Figure 6.5**).

Exhibit 6.2

Site Development Project
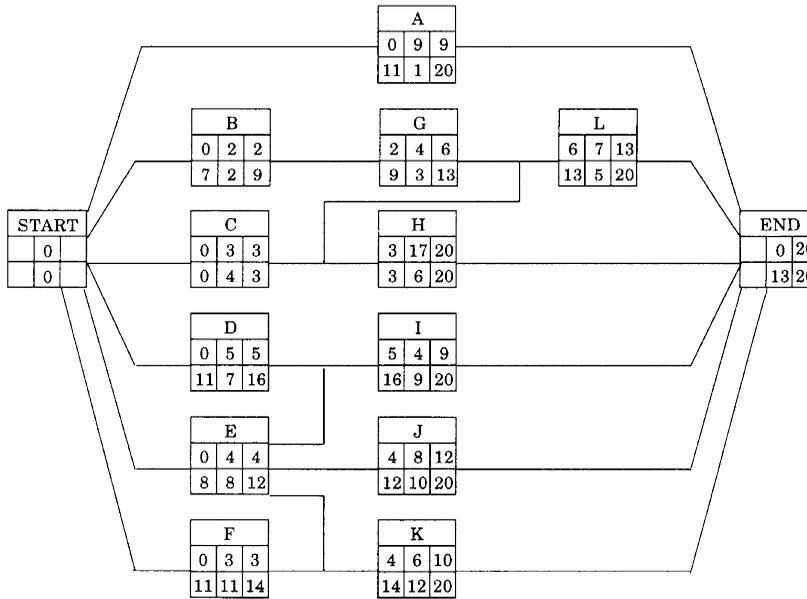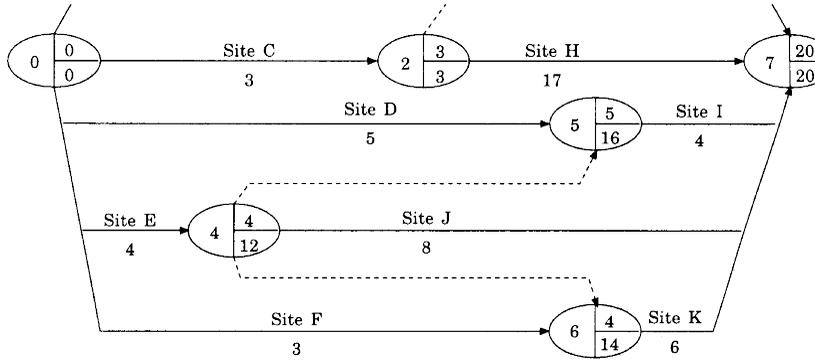
❑ 6.2 BAR CHART METHOD FOR WORK SCHEDULING OF SIMPLE PROJECTS

6.2.1 Bar Chart Method

Simple projects can be scheduled directly in the bar chart format by experienced hands. However, it is the network plans of complex projects and large-size repetitive projects that needs to be scheduled using scheduling techniques. Nevertheless, all time schedules are finally presented in the format of bar charts.

In the bar chart method, work is first split into activities and then these activities are listed in the order of their construction priorities, generally on the left hand side column, while the time scale

---

Figure 6.2

Site Development Project: Summary Earliest Start Time Schedule

No.	Activities	Working Weeks										
		2	4	6	8	10	12	14	16	18	20	
1	Task C, H	C		H								
2	Task B, G, L	B	G		L							
3	Task E, J	E		J								
4	Task F, K	F	K									
5	Task D, I	D		I								
6	Task A	A										
	Dozers Requirement	6 6	6 5	6 6	6 6	6 4	3 3	2 1	1 1	1 1	1 1	

shows project calendar, which can be plotted horizontally on the top and/or bottom of the chart (**Exhibit 6.1** shows the scale on the top).

The chart can be vertically divided into two divisions. While, the left division group activities are generally listed in the sequence of their execution and contains the data relating to activities, on the other hand,the right division depicts calendar and bars of scheduled activities. Graphically, the vertical segments of a bar chart can be organised in any of the following ways, also see **Appendix F** for various type of layouts:

- Activity description, data and calendar—This is a commonly adopted sequence;
- Activity description and calendar—This is used where data is omitted;
- Calendar with activity (or work package or task) only with description written inside or at the end of the bar—It is particularly useful for making a schedule for a large project; and
- Data followed by calendar with description inside or at the end of the bar—this facilitates scheduling of long duration projects.

The bar against each activity represents its work schedule. The start of the bar marks the commencement of the activity and the end of the bar marks its completion. The length of the bar on the

Figure 6.3

Site Development Project: Summary Latest Start Time Schedule

No.	Activities	Working Weeks									
		2	4	6	8	10	12	14	16	18	20
1	Task C, H	C		H							
2	Task B, G, L						B	G		L	
3	Task E, J						E		J		
4	Task F, K							F		K	
5	Task D							D		I	
6	Task A							A			
	Dozers Requirement	1 1	1 1	1 1	1 2	3 3	3 6	6 6	6 6	6 6	6 6

calendar scale represents the duration of the activity. Horizontally, each row represents the activity description and activity data,while, the rectangular shape bar represents the activity schedule.

The time base of bar charts and all scheduling techniques is the project calendar. Generally, this calendar covers the project's construction span from the start date to the final completion date. It specifies the dates when the activities are scheduled. The Bar Chart Calendar is divided into months, weeks, working days, weekend, non-working days, and holidays. The calendar weeks may have the standard five or six working days. The detailed calendar also highlights the working days and, non-working days, such as the weekends and national and other holidays, as applicable. The project calendar and its parts are invariably represented in a formatted horizontal bar as shown in various exhibits of this chapter and **Appendix F**.

6.2.2   Merits and Limitations of Bar Chart Technique

The prerequisite for preparing a Bar Chart is that the person drawing a Bar Chart must be the one who has experience in similar projects. Bar charts are easy to plot, comprehended, and are most

Figure 6.4

Site Development Project: Summary Smoothened Resources Time Schedule

No.	Activities	Working Weeks									
		2	4	6	8	10	12	14	16	18	20
1	Task C, H	C		←————			H	————→			
2	Task B, G, L	B		G		←	L	→			
3	Task E, J		E		←	J	→				
4	Task F, K							F	←	K	→
5	Task D, I		D		I						
6	Task A				←		A	→			
	Dozers Requirement	4 4	4 4	4 4	4 4	4 4	4 5	4 3	3 3	3 3	2 2

appropriate for presenting of schedules. However, as a planning technique, the bar chart is not suitable for complex projects due to the following reasons:

1. It does not reflect the relationship between various activities, which are a common feature of all complex projects, unless a time scale network is plotted.
2. It cannot identify and highlight the emerging critical tasks that need special attention for preventing schedule slippages, time overruns, contractual disputes, and other bottlenecks.
3. In complex projects, time durations often are educated guesses. Any change in schedule or time duration would require redrawing of the multi-task bar chart schedule.

Thus, it can be said that the bar chart format is most useful for presenting schedules, but as a planning technique, it is not suitable for planning complex projects.

The advancements in technology and the speed of execution of modern complex projects have made the traditional bar chart planning approach outdated and inadequate to cope with the complexities of modern construction. However, it is the time schedule that defines the time plan of work for implementation and not the Network Plan. The method of conversion of a Network Plan into a bar chart schedule is described in subsequent paragraphs.

Figure 6.5

Site Development Project: Summary Resources Limited Schedule

Activ- ities	Working Weeks												
	2	4	6	8	10	12	14	16	18	20	22	24
Task C, H, I	C		H								I	
Task B, G, D, L, K	B	G		D		L			K			
Task E, F, A, J	E		F		A			J				
Doz- ers Re- quire- ment	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3	3 3 3 3

❑ 6.3 NETWORK-BASED COMPLEX PROJECT SCHEDULING METHOD

6.3.1 Significance of Floats of an Activity in Scheduling Network

In complex projects, activities are sequenced using network techniques. A time analysed network depicts the start and completion times of critical and non-critical activities. The difference between the early and late start time of a non-critical activity is called as 'float' or 'total float'. Critical activities by definition have zero floats (or defined least floats). Floats provide the time margins, which can be utilised during scheduling of activities without affecting the time objectives for optimising resources utilisation. Scheduling methodology is described in subsequent sub-sections.

For scheduling, 'Floats' can be divided into three categories namely: total float (TF), free float (FF) and interference float (IF).

Floats of a Non-Critical Activity

EST			LFT
Duration		FF	IF
	←	Total Float	→
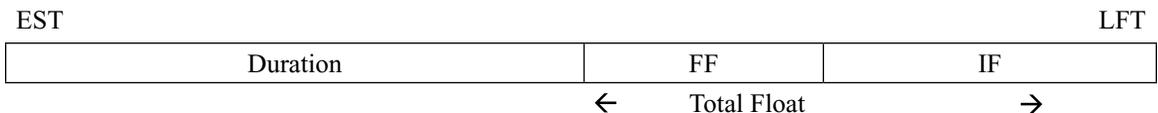
$$(LST = - \text{Duration})$$

The activities timing are defined and calculated as follows:
EST = Earliest Start Time
LST = Latest Start Time
EFT = Earliest Finish Time
LFT = Latest Finish Time

Total Float (TF).   It is the maximum period by which the start of an activity can be delayed from its earliest start time (EST) without affecting the project duration.

$$TF = LST \text{ of activity} - EST \text{ of activity}$$

Since

$$LST = LFT - \text{duration, and } EST = EFT - \text{duration}$$

Therefore,

$$TF = LST - EST$$
$$TF = LFT \text{ of activity} - EFT \text{ of activity}$$

Free Float (FF).   It is the maximum period by which the start of an activity can be delayed from its EST without affecting the EST of the successor activity(ies).

$$FF = EST \text{ of subsequent activity} - EFT \text{ of activity}$$

Interference Float (IF).   It is the difference in time between LFT of an activity and EST of the succeeding activity.

$$IF = LFT \text{ of activity} - EST \text{ of subsequent of activity}$$

Floats Relationship.   Add Interference Float and Free Float

$$\text{Interference Float} + \text{Free Float} = LFT \text{ of activity} - EFT \text{ of activity}$$
$$= \text{Total Float}$$

CPM/PERT Networks Float Calculations.   In CPM/PERT Networks, for an activity $(i - j)$ having duration 'd',

  1.   Total Float of activity $(i - j)$

$$TF = LST \text{ of activity} - EST \text{ of activity}$$

  But

$$LST = LET_j - d$$

$$EST = EETi$$

Therefore,

$$TF = LET_j - d - EET_i$$

2. Free Float of activity $(i - j)$

$$FF = EST \text{ of subsequent activity} - EFT \text{ of activity}$$

But

$$EST_j = EET_j$$
$$EFTi = EET_i + d$$

Therefore,

$$FF = EET_j - d - EET_i$$

3. Interference Float of activity $(i - j)$

$$IF = LFT \text{ of activity} - EST \text{ of subsequent of activity}$$
$$IF = LET_i - EET_j$$

4. Total Float of activity $(i - j) = FF + IF$

PNA Networks Float Calculations. In PNA Networks, consider two adjoining activities P and Q with duration of P as p and Q as q.

ESTp	EFTp
LSTp	LFTp
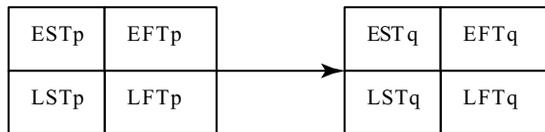
ESTq	EFTq
LSTq	LFTq

1. Total Float of Activity P

$$TF = LST_p - EST_p$$
$$TF = LFT_p - EFT_p$$

2. Free Float of Activity P

$$FF = EST_q - EFT_p$$

3. Interference Float of Activity P

$$IF = LFT_P - ESTq$$

4. Total Float of Activity P

$$TF = \text{Activity Interference Float} + \text{Activity Free Floats}$$
$$= LFT_P - EFT_p$$

Example. Take the CPM and PNA networks shown in **Exhibit 6.2** of a simple site development project.

Example: Float Calculations of Site F	
CPM Network	**PN Network**
TF of Site F = $LET_j - d - EET_i = 14 - 3 - 0 = 11$	TF of Site F = $LFT_p - EFT_p = 14 - 3 = 11$
FF of Site F = $EET_j - d - EET_i = 4 - 3 - 0 = 1$	FF of Site F = $EST_q - EFT_p = 4 - 3 = 1$
IF of Site F = $LET_j - EET_j = 14 - 4 = 10$	IF of Site F = $LFT_p - EST_q = 14 - 4 = 10$

Note: Mathematically, there are numerous ways for adjusting the floats of activities. For example, if an activity 'A' has a float of three days, and the parallel activity 'B' has a float of two days, then various schedules of these activities can be obtained by adjusting the floats between them. This means that activity A may consume 0, 1, 2, or 3 days float; and therefore, for each schedule of A, three schedules of B are possible. The procedure explained below can be adopted to systematically reduce the number of possible solutions for optimising resources.

6.3.2 Network-Based Scheduling Procedure

A schedule aims at completion of the project within stipulated time objectives by making use of optimum level of resources. Resource optimisation implies scheduling of resources according to the given pattern of their employment. Optimisation is achieved by suitably adjusting the schedule of non-critical activities with the help of available floats in such a manner that fluctuations from the desired pattern of resource utilisation are minimised.

Networks are scheduled to drive the start and completion date of each activity within time and resources constraints. The network activities can be easily scheduled for work, starting at the early start time or latest start time. The EST Schedule of this project is drawn in **Exhibit 6.3** and see also **Figures 6.2** and **6.3** to view dozer requirements implication of EST and LST schedules. However,time and resources constraints demand the work to be schedule so as to optimise employment of resources to the extent feasible.

The network based schedules can be broadly categorised into two categories, i.e., Time Limited Schedule and the Resources Limited Schedule. The procedure for drawing schedule in both categories is similar. The step by step methodology is given below.

The process of network scheduling is described step by step with the help of the CPM network of a simple site development project in **Exhibit 6.2**.

The scheduling of network plan involves the following steps:

- Outlining scheduling constraints;

Exhibit 6.3

Site Development Project
Earliest Start Time Schedule

Activity	Dura-tion	EET$_i$	EET$_j$	LET$_j$	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
														Working Period in Weeks										
C 0–2	3	0	3	3	1	1	1																	
H 2–7	17	3	20	20				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
B 0–1	2	0	2	9	1	1			IF															
G 1–3	4	2	6	13			1	1	1	1			IF											
L 3–7	7	6	20	20							1	1	1	1	1	1	1			FF				
— 2–3	0	3	6	13			-	FF	-		-	-	-	-	IF	-	-	-						
E 0–4	4	0	4	12	1	1	1	1				IF												
J 4–7	8	4	20	20					1	1	1	1	1	1	1	1			FF					
— 4–6	0	4	4	14					-	-	-	-	IF	-	-	-	-	-						
F 0–6	3	0	4	14	1	1	1	FF				IF												
K 6–7	6	4	20	20					1	1	1	1	1	1				FF						
D 0–5	5	0	5	16	1	1	1	1	1				IF											
I 5–7	4	5	20	20						1	1	1	1				FF							
R 0–7	9	0	20	20	1	1	1	1	1	1	1	1	1				FF							
— 4–5	0	4	5	16					FF	-	-	-	-	-	IF	-	-	-	-	-				
Total Dozers Required per Week					6	6	6	5	6	6	6	6	6	4	3	3	2	1	1	1	1	1	1	1

Dozer Requirement Profile

6
5
4 — Optimum Requirement = 4
3
2
1

Week No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20

- Tabulation Floats of Activities in Order of Sensitivity;
- Scheduling critical activities at their EST;

- Scheduling non-critical activities;
- Prepare Earliest Start Time Schedule and plot floats available for non-critical activities;
- Determining most vital resource scheduling criteria;
- Optimising other resources; and
- Validating Time Objectives.

Process of preparing two types of network based schedules, i.e. Time limited Schedule and the Resources limited Schedule is covered in the following paragraphs. It would have been ideal to illustrate the scheduling procedure with a major project in the text, but due to space limitations, the process of network scheduling is described step-by-step with the help of a simple Site Clearance Project CPM network in **Exhibit 6.2**. This has been followed by more examples on work scheduling.

6.3.3 Time-Limited Network Schedules

Outlining the scheduling assumption and constraints.   Assumptions are pre-supposed data, facts or presumptions which the planners believe to be true and these are considered without proof. The constraints are restrictions relating to time, resources, construction methodology or constractual conditions. The following assumptions and constraints are considered while scheduling the CPM network of the Site Development Project:

a. The date of commencement of work is January 1, 1990.
b. Four bulldozers in excellent working condition are available for the work. However, due to restricted space, not more than one dozer team can work at any site at a given time.

Further, in case of a breakdown of dozers, their replacement can be provided by hiring dozers locally.

a. Compressors are available on demand.
b. Five working days have been considered in a calendar week, leaving the rest of the days as spare, reserve, holidays or bad weather days.

Tabulation of floats of activities in order of sensitivity.   Floats provide the time margins, which can be utilised during scheduling of activities without affecting the time objectives. The amount of float available is a measure of the sensitivity of the activity, with less float meaning a higher sensitivity to delays.

   The float tabulation has a twofold purpose:

- To serve as a ready reckoner in order to determine the time margin available for each non-critical activity; and
- To calculate the order of sensitivity of the activities for charting during scheduling. Critical activities have zero floats and are the most sensitive activities.

Table 6.2

Site Development Project: Float Table

S. No.	Activity Code	Site	Duration	Event Timings			Total Float	Inter Float	Free Float	Sensitivity Rank
				EET_i	EET_j	LET_j				
1	0-2	C	3	0	3	3	0	0	0	1
2	2-7	H	17	3	20	20	0	0	0	2
3	0-1	B	2	0	2	9	7	7	0	3
4	1-3	G	4	2	6	13	7	7	0	4
5	3-7	L	7	6	20	20	7	0	7	5
6	2-3	Dummy	0	3	6	13	10	7	3	*6
7	0-5	D	5	0	5	16	11	11	0	12
8	5-7	I	4	5	20	20	11	0	11	13
9	0-7	A	9	0	20	20	11	0	11	14
10	0-4	E	4	0	4	12	8	8	0	7
11	4-7	J	8	4	20	20	8	0	8	8
12	4-5	Dummy	0	4	5	16	12	11	1	15
13	0-6	F	3	0	4	14	11	10	1	*10
14	6-7	K	6	4	20	20	10	0	10	11
15	4-6	Dummy	0	4	4	14	10	10	0	9

Note: For activities marked with asterisk (*), continuity of chain of activities is given preference over extent of availability of float, while labelling rank of sensitivity.

The float table for the site clearance project and the order of sensitivity is shown in **Table 6.2**. The following points may be noted:

a. The order of sensitivity shows the availability of float in descending order. Thus, a higher sensitivity means lesser float.
b. For activities having the same amount of total float; interference float is considered to determine the order of sensitivity.
c. For activities having the same amount of interference float; the path of activities is taken as a guide.
d. The dummy activities, where applicable, must also be listed and given appropriate numbers.

Listing the activities in order of sensitivity in the float table or directly in the scheduling chart can proceed as follows:

a. First, list all critical activities in a serial order commencing from the start event to the end event.
b. Next, list all activities of the sub-critical path, preferably following the numerical order of the activity code, even if slight adjustment may have to be made in the order or sensitivity.

    c.   Finally, list remaining chains of activities in the ascending order of availability of float of each activity. Some minor inaccuracy in the order of listing of activities does not materially affect the scheduling process.

With experience, the preparation of float table can be dispensed with and the order of listing based on the degree of sensitivity can be directly determined from the network. This data can then be reflected into the EST schedule.

Develop the ESD schedule by listing activities in the order of sensitivity.   The Earliest Start Time (EST) schedule of the Site Development Project is shown in **Exhibit 6.3**.
This format may vary with the nature of the project and types of resources that needs to be forecast. The following steps are involved:

- List all activities in the scheduling chart with connected durations and event times, in order of their sensitivity, as calculated in **Table 6.2**;
- Against each activity starting from EET mark the activity duration. Note first division of calendar starts with 1 and not zero (ESD = EST + 1). Accordingly add 'one' to all start timings to obtain start date of calendar schedule. For example, start of activity 2–7 (H) is 3, but while scheduling its start date, the bar commences at the end of 3 and beginning of 4. In simple words, Earliest Start Date = Earliest Start Time + 1;
- Draw free floats and interference floats against each activity;
- Identify the most critical item of resources required for performance of each activity (dozers in case of the Site Development Project); and
- Aggregate the critical resource date-wise.

Note: The procedure for drawing LST schedule is similar to EST schedule.

Determining the scheduling criteria.   Resource analysis of the Site Development Project reveals that the cumulative requirement of dozers for 20 weeks duration of the project comes to 72 dozer weeks. Therefore, the average requirement of these machines (Dozers) worked out as 4 dozer weeks approximately or 4 dozers per day within the week. Since, the site has 4 new dozers and in case of any breakdown, the replacement can be easily provided by hiring.The desired level of dozer requirement for site development project can be taken as 4 dozers per day employed on 4 activities at the rate of one activity per dozen per day.

    The important resources that are required date-wise and their estimated desired level can be plotted graphically to depict the loading pattern of resources. The area above and below the desired resource profile give the typical peaks and valleys look. Both sides of the desired resource level line indicate the possible area that needs adjustment (see **Exhibit 6.3**).

Scheduling critical activities at their ESD.   For the project to be completed on time, all critical activities have to commence at their ESDs and the resources required should have to be earmarked, accordingly. The ESD schedule developed in **Exhibit 6.3** has critical activities already

scheduled to be start with ESD. The extent of remaining resources that needsleveling can then be easily assessed by subtracting the required resources date-wise for purpose of critical activities from the desired level of resources.

Scheduling the non-critical activities in ESD schedule to optimise resources. The procedure for scheduling non-critical activities can be divided into the following two stages:

1. Schedule non-critical activities in order of sensitivity at EST till loading does not exceed the desired optimum resource level (**Table 6.2**), i.e., 4 dozers per unit of time.
2. Take the next non-critical activity in the order of sensitivity, and suitably schedule it within the desired level of vital resource by:

- Consuming free float (if available) to smoothen resources. Note that the EST of the subsequent activity(s) in the chain is not affected;
- If free float is not available, then utilise interference float and adjust the EST of subsequent affected activity(ies); and
- If available floats are not sufficient to smoothen resources, then adjust floats existing in the already scheduled activities.

3. Proceed similarly, with the next non-critical activity and continue till all the activities are scheduled.

Let us again consider the case of the Site Development Project. The time-limited optimum resources schedule this project upto Activity 6–7 is shown in **Table 6.2**. As can be seen from this, the schedule of work up to activity 6–7 does not cause overload from the desired level of resource (dozers). The scheduling of remaining non-critical activities can be carried out as follows.

Activity 0–5. The starting activity at EST causes overload. However, there are many ways of scheduling this activity without causing overload. Assuming that the continuity of work in a chain is to be maintained, the two options are:

Option 1. Schedule activity 0–5 starting from the eleventh week (after completion of activity 6–7). Its implication is that one dozer will remain idle in the fourth week, or,

Option 2. Reschedule the non-critical activities 0–6 and 6–7, with activity 0–6 starting in the tenth week (after completion of activity 6–7).
Implications of the above, are also to be examined from the construction priority and slippage of completion date angles. Considering these factors, the activity 0–6 and activity 6–7 are rescheduled as per Option 2 above, and activities 0–5 and 5–7 are scheduled at their earliest start.

Remaining activities. Proceeding similarly, activity 0–7 and dummy activity 4–5 can be rescheduled as shown in **Exhibit 6.4**.

Exhibit 6.4

Activity No	Code	Resources DZ	CP	Duration	EET_i	LET_j	LET_j	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20
																											Working Period in Weeks
1	0–2	1	–	3	0	3	3	1	1	1																	
2	2–7	1	–	17	3	20	20				1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	0–1	1	–	2	0	2	9	1	1				IF														
4	1–3	1	–	4	2	6	13			1	1	1	1				IF										
5	3–7	1	1	7	6	20	20							1	1	1	1	1	1	1				FF			
6	2–3	–	–	0	3	6	13					FF	-	-	-	-	-	-	-	-							
7	0–4	1	–	4	0	4	12	1	1	1	1				IF												
8	4–7	1	–	8	4	20	20					1	1	1	1	1	1	1	1								
9	4–6	–	–	0	4	4	14												IF	-	1						
10	0–6	1	–	3	0	4	14												1	1	1						
11	6–7	1	–	6	4	20	20															1	1	1	1	1	1
12	0–5	1	1	5	0	5	16	1	1	1	1	1						IF									
13	5–7	1	1	4	5	20	20						1	1	1	1						FF					
14	0–7	1	–	9	0	20	20										1	1	1	1	1	1	1	1	1		
15	4–5	–	–	0	4	5	16					F	-	-	-	-	-	IF	-	-	-	-	-				
Total Dozers Required Per Week								4	4	4	4	4	4	4	4	4	4	4	5	4	3	3	3	3	3	2	2
Week No.								01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20

Charting schedule.   Generally, schedules are plotted graphically on bar charts. These bars may also show the extent of total float and free float available against each activity. A bar chart is easy to read, understand, and communicate.

The activity data segment contains a number of columns, where each column contains basic data relating to activity schedule and connected resources. Such data includes, work quantity, activity duration, earliest start date, latest start date, earliest finish date, latest finish date, and schedule time constraints. Schedule data may also include resources, cost, and earned value. These are needed to draw bar charts and resources profile. The activity data reflected in the bar chart should be restricted to the barest minimum, depending upon the purpose of the bar chart.The various types of schedule layout, which can be easily drawn using Project Management software, are shown in **Appendix F**.

A word of caution.   Scheduling is not a mere mechanical process, it needs construction experience. The methodology for scheduling of non-critical activities described above should be viewed only as guidelines. In particular, the following should be kept in mind while developing a schedule:

1. Schedule activities in a realistic manner by maintaining the continuity of work. Avoid splitting up of activities, uneconomical shifting of resources, and frequent changes in the organisation of work gangs.
2. Consume less float of activities that carry higher risk of time slippages, and vice versa. Consume free float in preference to interference floats as free floats do not affect start of subsequent activities.
3. Do not omit dummies, as floats in dummies get altered after the floats of their preceding activities are consumed. These changes in float of dummies may affect start of the subsequent activities.

Optimising other resources.   The first estimate of resource optimisation is derived by using the vital items of resources (dozers). Based on this schedule other important resources are datewise aggregated and compared with the desired level. The loading profile is then plotted and the desired resource line is drawn to get a pictorial representation of the comparison. These resources are smoothened or rounded off as far as possible, within the framework of resource constraints till a suitable schedule of all the resources is achieved.

During rescheduling, free floats should be consumed first, even overlooking the order of sensitivity, as they do not alter the EST of subsequent activities. Whenever, interference float is utilised, the first step should be to change the ESTs of affected activities.

Validating the project time objectives.   Validation means verification of the achievement of project objectives. Before the work programme based on network time schedule is finalised, it should be validated to ensure that it meets the purpose for which it is drawn. In particular, the achievement of project objectives, of time and resource constraints should be studied carefully and the project management apprised of any limitation or implications in the critical stages of the project.

6.3.4   Resources-Limited Network Schedules

Normally, the resources should be allotted the optimum resource schedule, but this may not always be possible. There can be many slippages; such as, a particular machine may not be available in the market or the resources earmarked earlier may have to be shifted to another project. The network schedule provides the measure of resources required date-wise and also gives the implications in case, of any change in allocation. For the Site Development Project, the schedule based on availability of three dozers is shown in **Exhibit 6.5**. It may be noted that the project duration has increased to 24 weeks and procedure for scheduling is similar to that described in Section 6.3.3.

6.3.5   Scheduling Networks of Repetitive Works

The repetitive projects contain a large number of similar activities, each of which is organised into work-units or work-centres with assigned manpower, equipment, and other resources that are necessary for its accomplishment. In case of similar activities, these organised work-units continue to work till the completion of the same types of job. The work schedule of these work-units can be easily derived from the project networks.

   For example, consider the four-raft construction network depicted in **Exhibit 5.2**. It can be easily scheduled by first scheduling the critical activities and then suitably adjusting the non-critical activities by maintaining continuity in employment of each activity resource.

   Take the case of education buildings construction network depicted in **Exhibit 6.5**, involving the construction of one primary school, one high school, one KG school, and one nursery school. This network was developed by logically interconnecting the activities of each school, which is listed in the order of construction priorities.

   The schedule of work of the education buildings is given in **Exhibit 6.6**. It may be noted that the repetitive-type network is drawn for projects having only limited number of similar activities. When the number of repetitive activities becomes very large, then it is preferable to use the 'Line–of-Balance' technique for scheduling them.

❑ 6.4   LINE-OF-BALANCE BASED REPETITIVE PROJECTS SCHEDULING TECHNIQUES

6.4.1   Line-of-Balance Method for Scheduling Repetitive Projects

The LOB activity schedule chart shows the graphical plan of work execution in linear or 'S' curve shape. These graphs representing the work cycles are referred to as 'cyclographs' or 'cyclograms'. The time unit (day or week) in cyclographs are represented along the horizontal axis, while, the vertical axis shows the number of similar work units of the project. The time unit reflected on the horizontal axis can further be divided into calendar months (or weeks) after assessing the working days that are available in each month. To quote an illustration, the LOB schedule of Raft Foundation work packages of 2000 apartments housing complex project is drawn in **Exhibit 6.7**.

Exhibit 6.5

Activity Code No	Resources DZ	CP	Duration weeks	EET i	LET i	LET j
C 0-2	1	–	3	0	3	7
H 2-7	1	–	17	3	20	24
B 0-1	1	–	2	0	2	13
G 1-3	1	–	4	2	6	17
L 3-7	1	1	7	6	20	24
2-3	–	–	–	0	3	17
E 0-4	1	–	4	0	4	16
J 4-7	1	–	8	4	20	24
4-6	–	–	0	4	4	18
F 0-6	1	–	3	0	3	18
K 6-7	1	–	6	4	20	24
D 0-5	1	1	5	0	5	20
I 5-7	1	1	4	5	20	24
A 0-7	1	–	9	0	20	24
4-5	–	–	0	4	5	20

Working Period in Weeks (bar chart across weeks 01–24)

Week No.	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Total Dozers Required Per Week	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Dozer 1: C, H, IF

Dozer 2: B, G, L, I

Dozer 3: E, F, D, A, J, K

Exhibit 6.6

2000 Housing Units Project
Summary Schedule of Educational Building

Working Period in Weeks

No.	Work Description	Week No.	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75
1.	Foundations Wings 1 & 2		PS			RS		KS		NS								Foundation Team
2.	Foundation Portals			PS			HS										
3.	Structure Gymnasium				PS			HS										Gymnasium Structure Team
4.	Structure Wings 1 & 2					PS			HS		KS		NS					Wings 1 & 2 Structure Team
5.	Blockwork & Internal Plaster								PS		HS	KS	NS					Blockwork & Plaster Team
6.	External Plaster								35 37 PS		HS 45 47 50 52 55 57	KS NS					
7.	Ducting & Wiring						Ducting & Wiring Team										
8.	AC Equipment							AC Equipment Crew									
9.	Roof Treatment							Roof Treatment Team									
10.	Tiling & Surface Preparation						Tiling & Painting Team			PS		HS	KS	NS			
11.	Carpentry & Joinery						Carpentry & Joinery Team			PS		HS	K	N			
12.	Painting & Fittings					Finishing, Fittings & Fixtures Team					PS		HS	KS	NS		
	Weeks Cumulative		5	10	15	20	25	30	35	40	45	50	55	60	65	70	75

Exhibit 6.7

The LOB technique is originated in the manufacturing industry during the Second World War. It is primarily used for planning, scheduling, and controlling projects that involves a large number of repetitive works, such as similar buildings and multi-storied skyscrapers, and the linear type segmented works like roads, airfields, tunnels, and pipelines. It enables the optimum utilisation of resources, improvement in work efficiency, and interference-free scheduling of a wide range of activities. On the whole, the LOB technique is a simple scheduling tool that demonstrates the inter-relationship and caters for buffers between activities. LOB enables optimum employment of uninterrupted and efficient utilisation of significant resources. LOB data can be computerised facilitating easy monitoring and communication of data.

6.4.2   LOB Technique's Fundamentals

The following relationships can provide the framework for developing the LOB schedule; these are illustrated with an example.

1. Duration construction Phase (Dcp):

$$\text{Dcp} = \text{Project contract period} - \text{Mobilisation period} - \text{Reserve time}$$

2. Single unit construction duration (one building construction cycle) derived from CPM network (Du) = Sum of duration of work packages on critical path (without buffers).
3. Activity Crew output per unit of time = 1/Activity duration.
4. Project minimum construction time with one gang per work package/activity in accordance

with one building CPM Network.

$$D = Du + Dc\ (N-1) + B$$

Where:

D_p = Project minimum construction time without repetition of control activity

Du = Construction time of a single building construction cycle as analysed from its CPM Network

Dc = Longest duration activity in the network is called control activity as it is critical activity.

N = Number of buildings

B = Buffers

5. Project contract construction period, Dcp after considering B and repetitions (n) of control activity by increasing its number of crews to n.

Dcp = Project completion time within repetition of control activity

$= Du + B + (N - 1)\ Dc$/No. of repetitions

$= Du + B + (N - 1)\ Dc/n$

Subject to rate of construction of all preceding activities should preferably be equal to or greater than the rate of control activity after considering its repetition. Where,

$$n = (N - 1)Dc/(Dcp - Du - B)$$

6. Development of the time limited LOB scheduling chart depends upon four main factors in a Single Unit Construction, i.e. the activity start time, the activity duration, the activity rate of build up, and the buffer (or float) available prior to starting the subsequent activity. The scheduling chart showing number of work units (cumulative) that are planned for completion have linear or 'S' curve shape. In general, the preparation of a LOB Chart involves the following steps; however, number of steps can be omitted with experience and practice:

   a. Develop CPM or PDM network of the activities of a Single Construction Unit of the project and re-group activities into work packages. A Single Construction Unit is a group of activities/work packages that constitute an end product or deliverable, such as a housing unit.

   b. Insert buffers between activities in a single construction unit. The buffers are provided to cater for unforeseen delays in completion of the preceding activity(ies) in a Single Unit Construction. Generally, buffers or lead time are included in the duration estimate of the work packages.

   c. Calculate the project construction completion time without and with repetitions of control activity. Estimate the unit minimum construction rate to complete the work in contracted time. The construction rate of preceding activities should be higher than control activity and those of succeeding activities should preferably be equal to or marginally less than the control activity.

  d. Develop Start Date, Completion Date, and Rate of Execution of each work package, by using one crew team for each work package and reducing duration of control work package is based on its repetitions to achieve nearly equal construction rate.

7. The preparation of LOB charts is illustrated here with the construction of 12 similar buildings within 78 weeks construction time. It is followed by a case illustration from the 2000 apartments, 334-module residential building construction project (6 apartments per module) with superstructure made up of pre-cast concrete components manufactured in a factory located at site

6.4.3   LOB Schedule Development Methodology Example

1. *Develop CPM or PDM network of the activities for a typical project cycle and regroup activities into work packages (as shown in* **Table 6.3***).*

Table 6.3

Work Packages of a Residential Building of the 12 Similar Building Project

Code	Work Package Description	Dur. (Wk)	Activities
FDN	Foundation	2	Excavation, base, footings, stub columns, plinth walls, back filling, ground floor slab
SSC	Super structure construction	9	First floor structure, second floor structure, roofing structure
BPR	Brick work, plaster and rough-in	3	Brick work, plastering, roughing plumbing and conduiting work
FCP	Flooring, carpentry painting	3	Screed, ceramic tiles, carpentry and joinery, preliminary paint
FFF	Fitting, fixtures, finishes.	3	Sanitary fitting, electrical fitting and fixes and final paint and finishes

1. Number of buildings =12, all durations are in weeks

2. Work package SSC with unit duration nine weeks is the control activity

Take the example of a 12 three-storeyed buildings construction project (N = 12). The project construction period, Dcp is 78 weeks. The network of one building construction unit shows its completion time as 20 weeks (Du). Its work packages with duration of each in weeks are given below:

```
        FDN            SSC              BPR          FCP      FFF
        -------->---------------------->------------>--------------->-------> ~
         2              9                3            3        3
```

First Unit Cycle Work Packages

Where

FDN = Foundation
SSC = Super Structure Construction
BPR = Brick Work, Plaster and Rough-in FCP = Flooring, Carpentry, Painting
FFF = Fitting, Fixtures, Finishes

Out of one building cycle construction, the duration of three-storeyed superstructure construction (SSC) work package is 9 weeks. It is the longest duration and is called control work package/activity.

2. *Calculate the completion time of project construction without repeating control activities*. Project Minimum Construction Time with single unit estimated work packages durations includes buffers and one crew team for each work package in accordance with one building unit CPM Network.

$$Dp = Du + (N – 1)Dc = 20 + (12 – 1)\ 9 = 119 \text{ weeks} \quad \text{(without buffer)}$$

Note: If there is more than one control activity, then the set of control activities is worked out similarly.

The LOB Chart project construction completion time without repetition of control activity is plotted using following guidelines:

1. Select the EST point of first activity/work package on the graph and draw pair of lines sloping equal to its rate of execution and width equal to its duration.
2. Proceed with the subsequent activities/work package, (providing buffers in between) till the activity/work package having the least rate of execution (slope) is reached.
3. Plot the lowest rate sloping line and mark its intersection with the top horizontal line of last buildings..
4. Starting from top point of intersection, move forward horizontally on the top line and identify the latest completion point of the subsequent activity as indicated by the setback chart.
5. From this activity, i.e. latest completion points draw line towards bottom line with slopes equal to the reverse slope of the activity.
6. Proceed similarly till all activities are scheduled.

The data used for plotting the above graph is shown in **Table 6.4**.

3. *Conceptualise the project construction completion time with repetitions of control activity*. Contract construction time is 78 weeks. In order to complete the project construction works in 78 weeks, it is necessary to resort to repetition (n) of the control activity with a view to increase its effective construction rate and also to cater for buffers totaling 9 weeks.

$$Dcp = Du + (N– 1)\ Dc/n$$
$$78 = 20 + (12 – 1)\ 9/n, \quad \text{or}$$
$$n = 11 \times 9/(78 – 20) = 99/58 = 0.17.$$

Table 6.4

Work Package Scheduling Data

Work Pkg Code	Dur. Wk	Start first House Wks	Finish first House Wks	Duration (N–2) Houses Wks	Start last House Wks	Finish last House Wks	Construction Rate= 12/ (C8–C4)	Constrn. Period = (C8–C4) Wks
1	2	4	5	6	7	8	9	10
FDN	2	0	0 + 2 = 2	20 →	2 + 20 = 22	22 + 2 = 24	12/24 = 0.50	24
SSC	9	2	2 + 9 = 11	90 →	11 + 90	101 + 9 = 110	12/108 = 0.11	108
BPR	3	80 − 3 = 77	110 − 30 = 80	30 →	110	110 + 3 =113	12/36 = 0.33	36
FCP	3	80	80 + 3 = 83	30 →	113	113 + 3 = 116	12/36 = 0.33	36
PPP	3	83	83 + 3 = 86	30 →	116	116 + 3 = 119	12/36 = 0.33	36

Therefore, employment of two crew teams to perform control activity so as to double its output and reduce its duration by half to complete the project, within the contracted construction period.

Note: The buffers are provided to cater for unforeseen delays in completion of the preceding activities. These are included in the estimated duration of work package.

4. *Develop start date, completion daTte, and rate of execution of each work package to complete project within time.* Considering the data generated in **Table 6.4** above using one crew team for each work package, the project duration works out as 119 weeks but the project construction period is 78 weeks.In order to complete this project in 78 weeks, proceed as under:

a. Identify control activity, which has least rate of execution and takes longest time duration for construction. It is SSC. Its rate of execution per week is 0.11.
b. Calculate minimum rate of execution of project for completing work within specified time as follows:

- Minimum rate of execution of each work package
 = No. of buildings/execution period in weeks.
 = 12/78 = 0.17/week for each work package.

Figure 6.6

**Rate of Construction of Each work Package:
A Graphic Representation (Not to Scale)**

Not to Scale
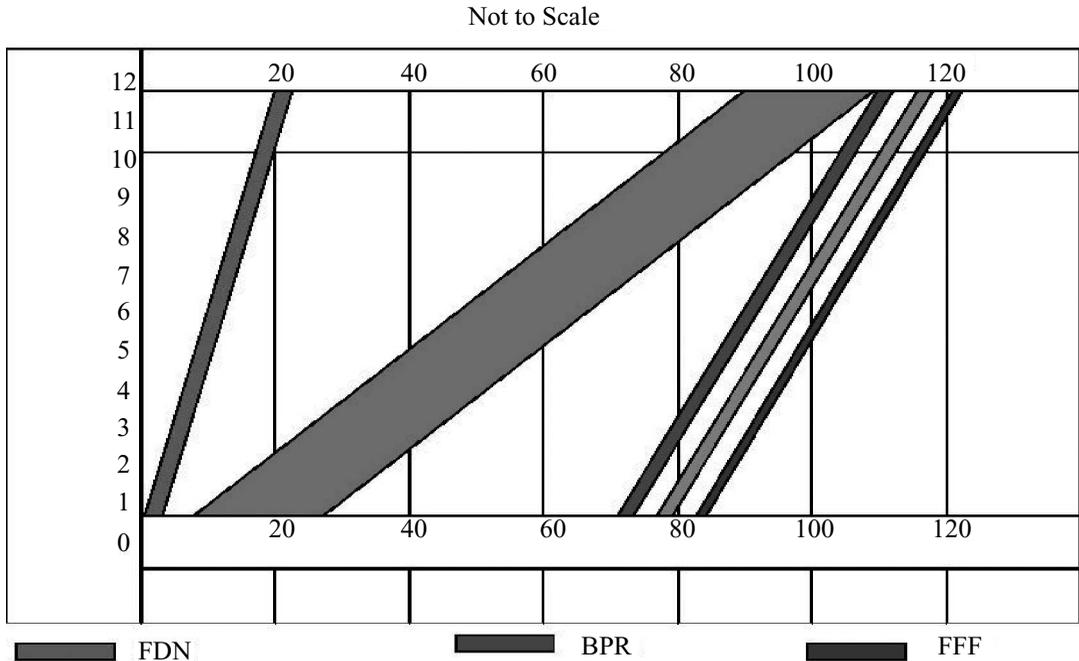
5. Hence any work package with rate lower than 0.17/week must increase its efforts to come upto minimum rate of execution of each work package. In this case, SSC work package (rate of execution 0.11) must employ at least two crews with equipment to make its rate of execution >0.17 to match minimum rate of execution of each work package project, i.e. say $2 \times 0.110 = 0.22$ with two crew teams.

This process of crashing project duration in case of example under preview in **Table 6.5**; it can be plotted graphically as LOB Chart:

Note:

1. Activities preceding the control work package must have the rate of construction equal to or higher than the control activity rate of execution.
2. For work packages succeeding control work package; the lead times, buffers, and rate of execution must be balanced in order to complete the project within time.
3. Preferable rate of execution of all work packages should be made nearly equal by crashing or stretching each work package duration and it should have suitable buffer, if feasible.

Graph of the time-limited resources schedule, with a uniform rate of construction of all work packages is given in **Figure 6.7**.

<div align="center">

____

Table 6.5

</div>

| Work Pkg Code	Dur. Wk	Start first House Wks	Finish first House Wks	Duration (N–2) Houses Wks	Start last House Wks	Finish last House Wks	Construction Rate = 12/ (C8 –C4)	Constrn. Period = (C8 – C4) Wks
1	2	4	5	6	7	8	9	10
FDN	2	0	0 + 2 = 2	20 →	2 + 20 = 22	22 + 2 = 24	12/24 = 0.50	24
*Buffer	2	0						
SSC(A)	9	2 + 2	4 + 9 = 13	36	13 + 36	49 + 9	12/52 = 0.23	52
SSC(B)	9	2 + 2	4 + 9 = 13	→	13 + 36	49 + 9	12/52 = 0.23	52
BPR	3	28 – 3 = 25	58 – 30 = 28	30 →	58	58 + 3 = 61	12/36 = 0.33	36
FCP	3	28	28 + 3 = 31	30 →	61	61 + 3 = 64	12/36 = 0.33	36
PPP	3	31	31 + 3 = 34	30 →	64	64 + 3 = 67	12/36 = 0.33	36
Reserve	78 – 67 = 11							

* Buffer included to delay start of SSC(A) and SSC(B) so as to start their construction after two FDN arecompleted. Further, if any activity, following control activity has duration higher than BRP of three weeks, say FCP has duration four weeks, then it will increase completion period unless the duration of FCP is crashed to three weeks by strengthen its crew.

6.4.4   Short Cuts Simplifying Development of LOB Schedules

1. **Simple repetitive projects**. Draw schedule of first construction unit after making adjustment for repetition in control activity and buffers along x-axis of first building unit and draw offset (reverse order) of this at the end of the last building row. Then join the start and finish of each work package/activity in the first building and last building. This will take the shape similar to **Figure 6.7**.
2. **Scheduling using project management software**. Develop PDM networks using project management software like Primavera Project Planner or MS Project, link precedence sequences horizontally; and link the similar preceding activities nodes vertically for the remaining cycles. It enables consistent resources employment. .

Figure 6.7

Building Construction Project Completion 60 Weeks Time: Limited Schedule
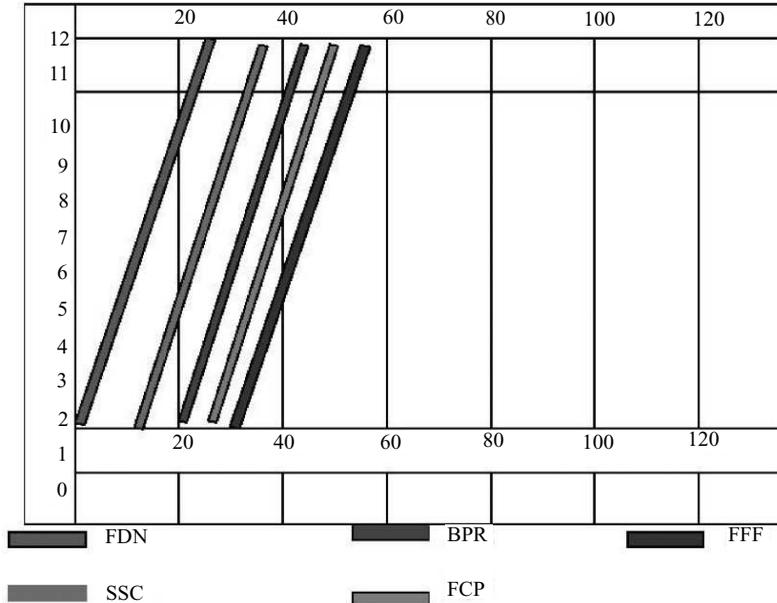
Not to scale

6.4.5   2000 Housing Project Planning Approach Using LOB Technique

Scope and Constraints.   The residential housing project involves the construction of 2000 apartments of 334 similar modules with six apartments per module. The construction is to be completed in 785 working days. The construction task is entrusted to the following three task forces:

- Foundation construction task force;
- Pre-cast superstructure production and erection task force; and
- Finishing task force.

Foundation Construction Task Force (Table 6.6).   The Work Breakdown Structure of one module of foundation is shown below. Each work cycle for construction of the foundation module is grouped into work-packages as follows:

The assigned task requires the production of producing one foundation per working day at peak level, subject to the following constraints:

1.   It includes learning period with each work package. In this the work commences in the first (M01) month and progresses gradually to one raft per day within two months.

Table 6.6

Foundation Construction Task Forces

Work Package	Detailed Activities
Base construction Task Forces	Layout, excavation, compaction, anti-termite treatment, PVC sheeting, shuttering and blinding concrete
Raft construction Task Forces	Layout, shuttering, reinforcement, raft concreting.
Plinth wall construction Task Forces	Raft curing, bitumen coating, reinforcement fixing, shuttering, wall concreting
Ground construction Task Forces	Preliminaries, backfilling, shuttering, mesh fixing, floor concreting

2. Two sets of conventional timber formwork for plinth walls that needs to be manufactured locally in the first month. The balance, which is the imported custom-made steel shuttering, is expected to reach the project site by the end of the third (M03) month.

3. The ground floor design is expected to be finalised by the end of the fourth (M04) month.

4. The manpower required for the plinth walls and ground floor can be inducted earlier, provided that it can be effectively utilised to increase the rate of progress of other foundation activities

Table 6.7

Foundation Work Package LOB Data

Wk Pkg	Dur. Days	Target Rate Per Day	Crew Nos.	Buffer Days
Base	6	1.2	8	-
Raft	6	1.2	8	12
P. Wall	8	1.0-from the receipt of Formwork.	8	12
G. Floor	8	1.0-from Approval of Floor Design	8	75

Note: The buffers are provided to cater for unforeseen delays in completion of the preceding workplace.

Residential Buildings Erection Task Force. The erection of superstructures is linked to the production of pre-cast concrete in the factory. The peak erection capability of the five erection teams at the project site is 5/6 modules per working day. The pre-cast superstructure erection schedule is given in **Table 6.8, Exhibits 6.8** and **6.9**.

Table 6.8

Rate of Precast Production in Modules/Month

| Period	First Month	Second Month	Third Month	Fourth Month	Fifth Month	Sixth Month	Total
M06 to M11	4	6	8	10	12	14	54
M12 to M17	15	16	17	18	19	19	104
M18 to M23	19	19	19	19	19	19	114
M24 onwards	19	19	19	5	-	-	62
Total							334

Exhibit 6.8

Residential Building Foundations Work Packages Construction Cyclograph (in Units of Models)

Exhibit 6.9

Modules Planned Cumulative

Time in Months from start of structure erection.
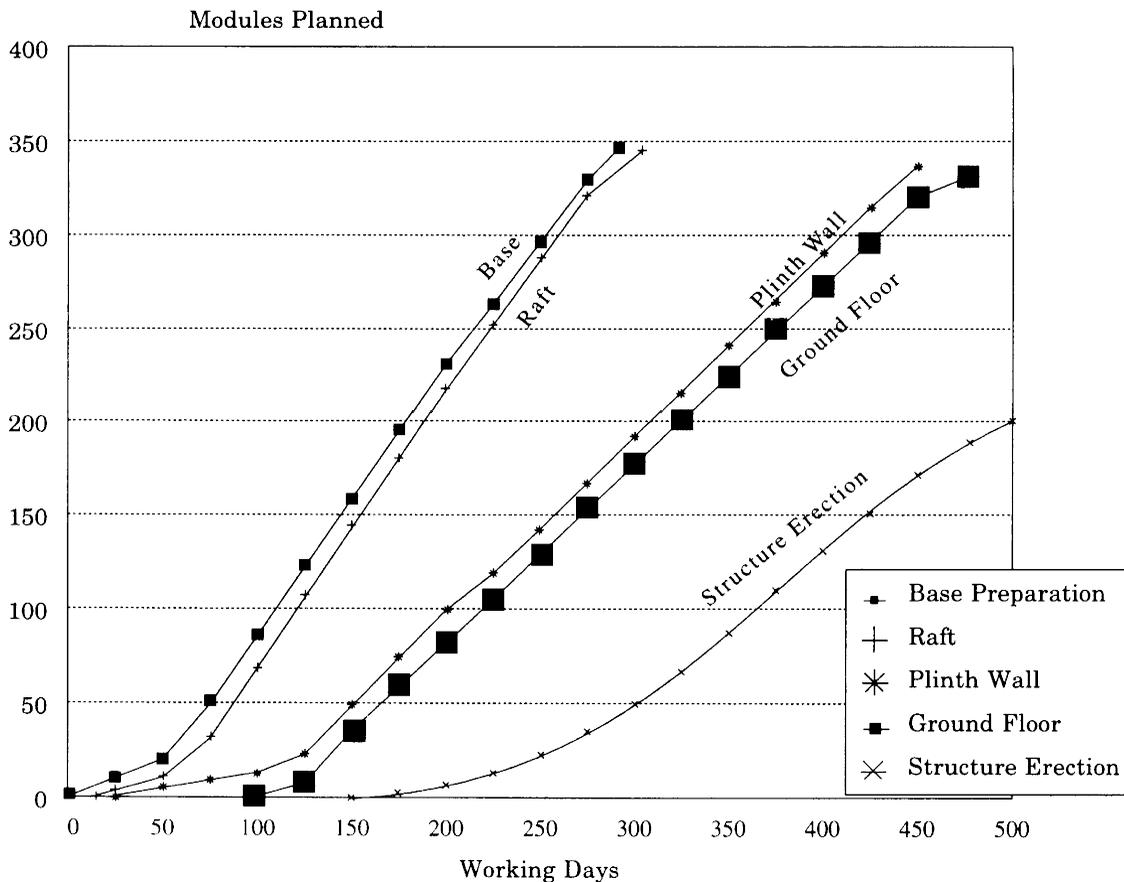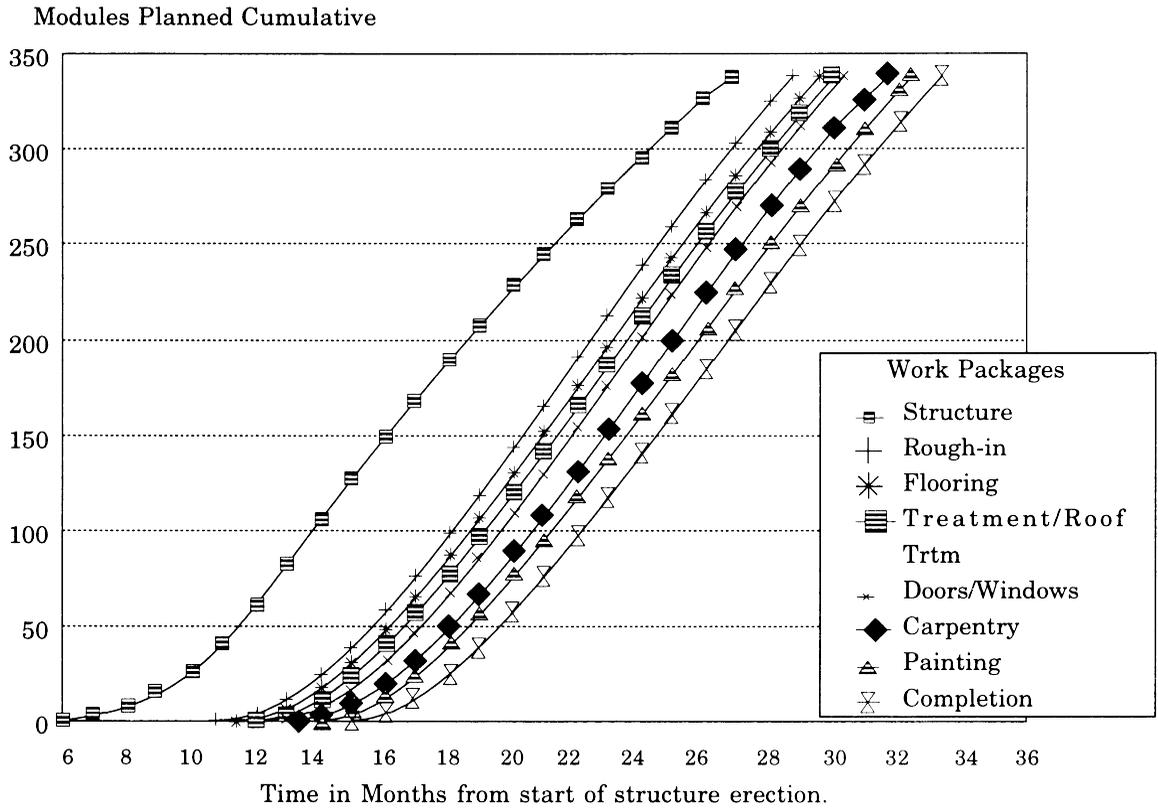
Residential Buildings Finishes Task Force. The finishes in the erected buildings are to be progressed at the rate of one module per day so as to complete the entire project at the earliest. These finishes can be broadly divided into the work packages indicated in **Table 6.9**.

Earliest the finishing work can start, is after a buffer of at least four months from the erection of the first module. Initially, the rate of finishes can be slow and then can increase gradually, till erection reaches its peak rate. Thus, the workers required can easily be forecasted. The rate of finishing key activities for early completion thus derived, from start of erection of structure is shown in **Exhibit 6.9**.

6.4.6 LOB Control Chart

The LOB control chart is used to monitor the work progress. In this, the vertical axis scale is same as that of the activity schedule chart, and each activity is represented by a column along the horizontal axis, as shown in **Exhibit 6.9**, drawn for controlling important finishing targets.

At a given point of time, the last date of each month, the number, and types of activities planned for completion, are read from the activity schedule chart and tabulated in the LOB control chart

inside each activity column. The line joining the horizontal segments of number of various activities, planned for completion on a given date, represents the line of balance for achieving the planned targets. The actual progress at the end of the month is reflected in the LOB control chart to determine variances from the planned targets.

The activity progress beyond the LOB line shows progress ahead of schedule, while, that below it, shows progress behind the schedule. The activities falling behind schedule are analysed to determine the degree of criticality. (The method of time control of repetitive projects based on LOB technique is covered in **Chapter 16**.)

Generally, where space permits, the LOB control chart and the activity schedule chart are plotted on the same sheet (**Exhibit 6.10**) and monthly targets are tabulated as shown in **Exhibit 6.11**.

❑ 6.5   RESOURCES SCHEDULING CONSIDERATIONS

6.5.1   Factors Affecting Resources Scheduling

The scheduling of a project plan has to take into consideration many variables like time, resources, and financial constraints. It is difficult to enumerate principles governing all such factors,which may vary from project to project. However, the guidelines given in the following can be considered for developing the work schedule of a project.

Time.   The availability of time is a crucial limiting factor in a project. More time implies less investment. Time and cost are correlated factors (refer **Appendix D**). There are three aspects of time, which have to be considered during scheduling:

a. Most of the projects carry time constraints in the form of imposed dates. These dates may include constraints on start and completion of activities. A schedule must meet the project time constraints, in such a way that project duration is not exceeded; such a Schedule is called *time limited schedule*.

b. The schedule must account for holidays, bad weather days, and the non-working periods. Further, affect of the working season on production efficiency must also be considered while scheduling activities and the schedule and connecting resources adjusted suitably. Such a schedule details the work programme for execution.

c. Scheduling must make use of the reserve of time available in floats of non-critical activities to reduce fluctuations in resource requirements or conform to a given predetermined pattern of resources. For minor fluctuations, working overtime may also be resorted to. The schedule prepared under resource constraints is termed as *resource limited schedule*.

Manpower.   Manpower is one of the main factors in successful execution of projects. No amount of automation or machinery can replace the manpower needed for completion of project. It cannot be treated like a commodity and cannot be dismissed or re-employed at will. Technical hands once employed are normally continued till their requirement ceases. The idle labour time is paid for and

Exhibit 6.10

**Residential Building Finishes Control: Using Line-of-Balance Techniques (in Units of Modules)**
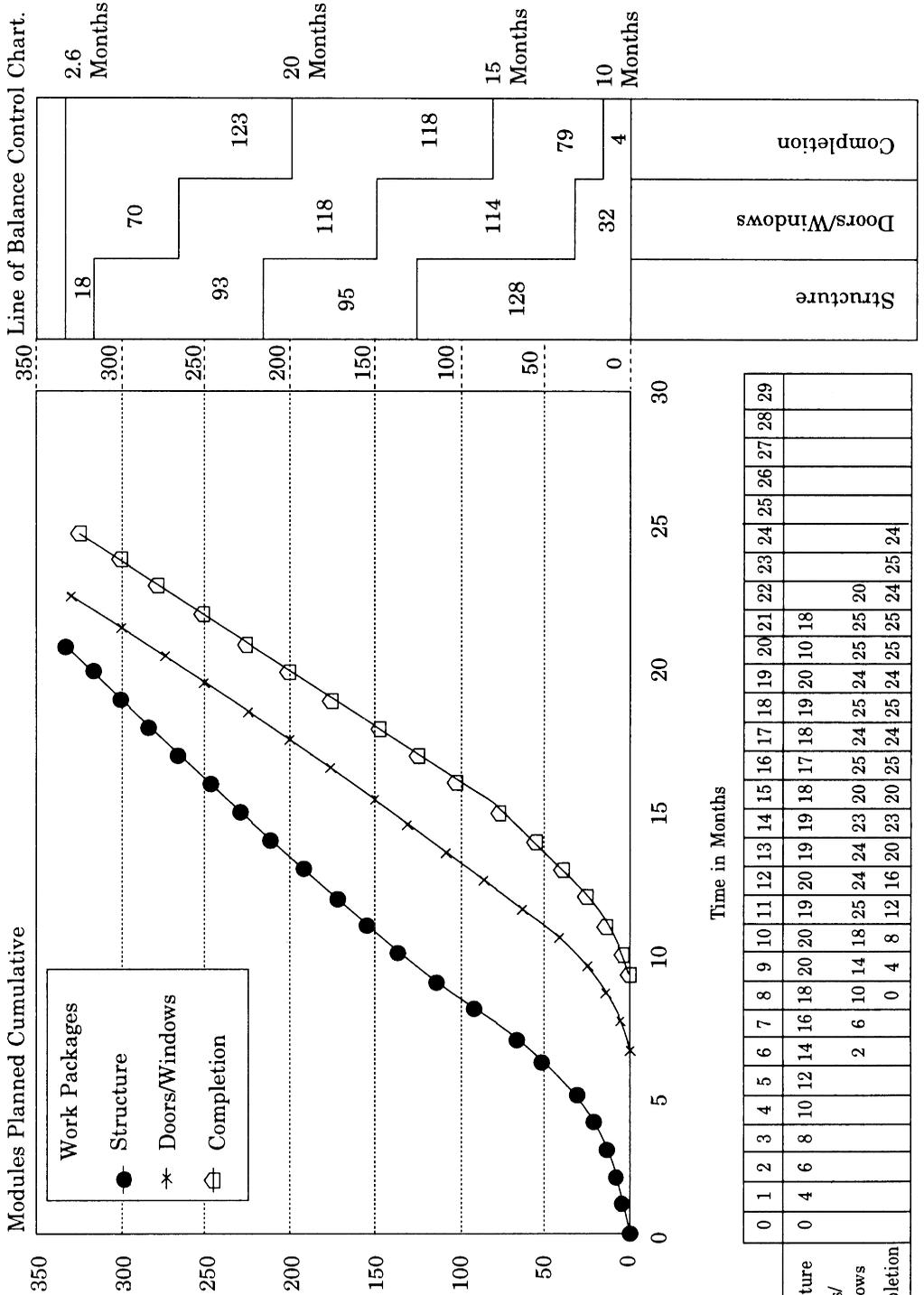
Line of Balance Control Chart.

	Structure	Doors/Windows	Completion	
350				
	18	70	123	2.6 Months
300				
250	93	118	118	20 Months
200				
150	95	114		15 Months
100	128		79	
50		32	4	10 Months
0				

Modules Planned Cumulative

Work Packages
- ● Structure
- ✳ Doors/Windows
- ⬠ Completion

Time in Months

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
Structure	0	4	6	8	10	12	14	16	18	20	20	19	20	19	19	18	17	18	19	20	18									
Doors/Windows									10	14	18	25	24	24	23	20	25	25	24	25	10	25	25	24	25					
Completion					2	6				4	8	12	16	20	23	20	25	24	24	24	20	24	25	24	24					

Exhibit 6.11

2000 Housing Units Projects
Residential Building Monthly Target Tracking Chart

Residential Building Monthly Target Tracking Chart

No.	Work Description	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
1	Base Construction	12	16	25	37	36	37	36	36	33	30	34	2									
2	Foundation Rafts	6	12	25	37	36	37	36	36	33	30	34	12									
3	Plinth Walls	5	5	5	12	25	24	24	22	20	23	24	25	24								
4	Ground Slabs					12	25	24	24	22	20	23	24	25	24	25	24	24	23	23		
5	Super Structure								4	6	8	10	12	14	16	18	20	20	19	20	19	19
6	Wiring										8		4	8								
7	Plumbing									4	8	12										
8	Air Cooling Ducts									4	8	12	16	20	24	25	24	24	24	24	24	23
9	Door Frames											4	8	12	16	20	24	25	24	24	23	20
10	Screeding											2	6	10	14	18	24	23	24	24	23	23
11	Roof Treatment													4	8	12	16	20	25	24	24	24
12	Terrazzo-Ceramic Tiles													4	8	12	16	20	25	24	24	23
13	Doors/Windows Shutters													2	6	10	14	18	23	23	24	23
14	Preliminary Paint													4	8	12	16	20	24	24	23	20
15	Carpentry/Joinery/Glazing													2	6	10	14	18	24	24	23	20
16	P.V.C. Tiles															4	8	12	16	20	24	23
17	Fittings/Fixtures															2	6	10	14	18	24	23
18	Final Completion																4	8	12	16	20	23

	Months	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan
	Working Days in a Month	25	24	25	25	24	25	24	24	22	20	23	24	25	24	25	25	24	25	24	24	22
	Working Days Cumulative	25	43	74	99	123	148	172	196	218	238	261	285	310	334	359	384	408	433	457	481	503

Table 6.9

Residential Building Finishing Works

Work Package	Activities Included
Rough-in	Wire pulling and circuit checking. GRC panel fixing and sealing of edges PVC and GI plumbing, A/C ducting, and staircase metal work, balustrade
Flooring	Screed, ceramic tiles
Roof Treatment	Insulation, polythene sheet separation layer, screed, primer and tarfelt.
Doors and Windows	Doors and windows and joinery including shutters
Carpentry	False ceiling, glazing, kitchen cabinet fixing and built-in wardrobes.
Painting, fittings and fixture	Surface preparation and preliminary painting, sanitary fittings, electrical fittings and fixtures, staircase and PVC handrail
Completion	Final painting, masonry decoration work, PVC tiling

the strikes and breakdown of work are kept in view by the management. The task efficiency of labour, weather conditions, nature of work, and the skills of the supervisors, affects labour productivity. The non-availability of suitable skilled labour is generally a limiting factor. The labour turnover, sickness, and absenteeism further aggravate the problem. The working hours, overtime, and other incentives have to be considered while deciding the manpower schedule. The management-labour agreements and the governing labour laws considerably, affect labour employment. A schedule cannot take care of all the variables but these can be reduced considerably, by working out a uniform trade category-wise manpower requirement schedule, or by fixing a pattern depending upon the manpower availability and working conditions.

Materials.   No project can ever be started without materials. Construction materials are increasingly becoming scarce and their procurement is a time consuming process. The schedule aids in forecasting of materials and their timely supply determines the economics and progress of work. One method could be, to stock materials well before they are required so as to ensure timely supply, but the stock inventory costs money. Generally, the inventory should be zero before the commencement and after the completion of the project. To go a step forward, this rule should be made applicable to each activity. But for certain materials, the procurement action can be based on the guiding principle that materials inventory must be kept to the minimum. In case of materials in short supply, the schedule may have to be based on availability constraints.

Machinery.   The availability of machinery is, normally, a limiting factor. For example, in an activity involving excavation, the schedule may specify a requirement of two dozers, but one may actually be available or allotted. This would entail a recasting of the whole schedule. In such cir-

cumstances, various alternatives like delay-penalty costs, cost of time crashing and the cost of procurement or hiring of additional machinery have to be weighed before making the final decision. The aim of machinery and equipment scheduling should be to find out the minimum duration schedule where the employment of equipment and machinery is systematically and uniformly distributed, based on its availability or allotment.

Capital.   Capital is the core of all project activities. The project management aims at economies and the contractor works for earning profits. The proper management of money results in savings, while, its improper use results in loss. For example, consider the investment implications of starting works at their EST and LST, as can be seen from the graph shown in **Figure 6.8**.

Figure 6.8

Total Project Expenditure
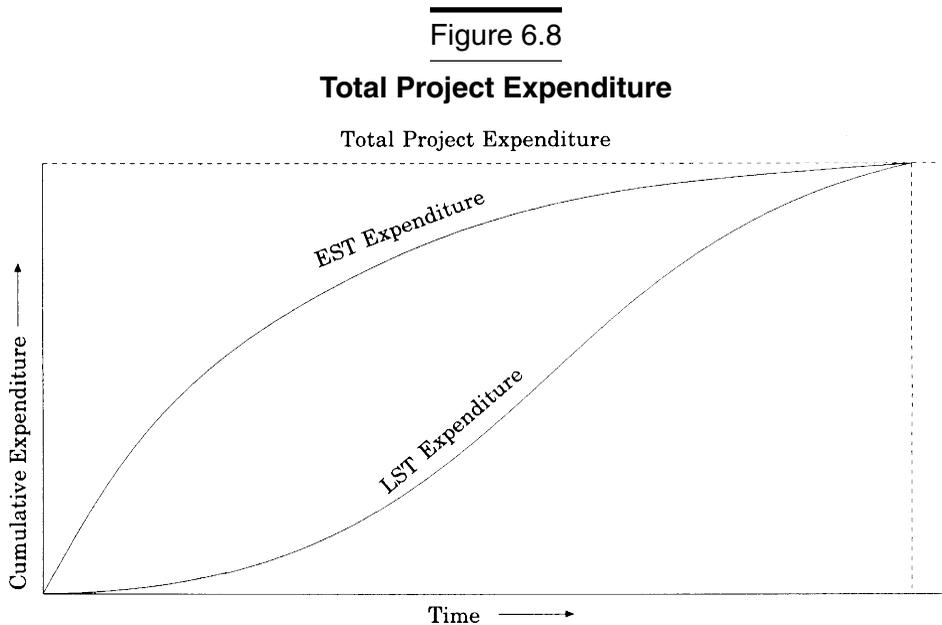
In the LST schedule, the large production costs get staggered over a longer period of time, thus reducing investments. This LST schedule may prove attractive to a builder because of least investment. Therefore, a builder's schedule, would generally aim to execute those jobs earlier, which are more profitable, involve least investment, and benefit cash flow. On the other hand, the client would aim at phasing of construction for early completion. The network schedule must balance these conflicting requirements.

6.5.2   Forecasting Inputs and Outputs

Why forecast resources.   The economies of projects depend upon the forecasts. This accuracy, in turn depends upon the experience and ability of the persons making the forecasts. The

forecasts are educated guesses based on assumptions and judgment. The assumptions made at the time of forecasting are based on the available information, which may or may not hold well in the future. Unforeseen situations may occur, which affect the decisions made at the time of forecasts preparation. In spite of the risk of proving wrong, forecasts for inputs and outputs should be made and reviewed at frequent intervals, as they assist in taking crucial decisions.

The work schedule forms the basis for making forecasts. The forecasts predict the future projections date-wise, in respect of input resources, production outputs, and cash flow.

Resources forecasting procedure. The work schedule forms the basis for making forecasts. The procedure for forecasting each item resource is similar. It involves the following steps:

a. Assess the required resources for each activity item-wise by making appropriate assumptions and using standard engineering constants. Write important items of resources in the scheduling chart under appropriate column or inside the bar representing the activity schedule.
b. Calculate the daily rate of expenditure of each item of resources,activity-wise. The rate of consumption would depend upon the nature of the activity. Mostly, the rate of consumption can be assumed to be constant and can be determined by dividing the resources required by the activity duration; sometimes, it may be expressed in terms of units of time, say, expenditure per four weeks.
c. Prepare the resources aggregate by adding date-wise the requirement of each item, as per the scheduled dates of activities. This is normally worked out on the schedule chart.
d. Determine date-wise, the cumulative requirement of resources. This data gives the forecast of resources.
e. Plot the forecast of resources graphically. Generally, the cumulative forecasts are in the form of S-shaped curve (**Exhibit 6.12**).

Note: It is not necessary to prepare the forecast of each item of resources down to the last nails, nuts and bolts. Forecasting, as discussed above, is a laborious process and should be restricted only to the important items.

Further, forecasting predicts the date on which the resources are required, but this must not be mixed up with the provisioning action. For example, the materials forecasts provide the planning programme, whereas, the indenting, purchasing, and inventories of the materials, must be based on the well-established principles of materials management.

Nature of input resources needing forecast. Inputs, in the form of resources; comprise men, materials, machines, and money. These are inducted into the project from time-to-time as the work progresses. The schedule of work provides the framework for forecasting these inputs, which can be directly identified with the activities. Some of the direct input resource forecasts, which can be developed from the work schedule, include the following:

Daily quantity of work execution forecast. The schedule of work can be used to forecast date-wise, the major items of work that needs to be performed, such as, their execution rate . These work include earthwork, reinforcement, shuttering, concreting, masonry, plastering, carpentry and

Exhibit 6.12

Site Development Project: Forecast of Input Costs and Work Done Value (in thousand dollars)

Amount in $000

Time in Weeks
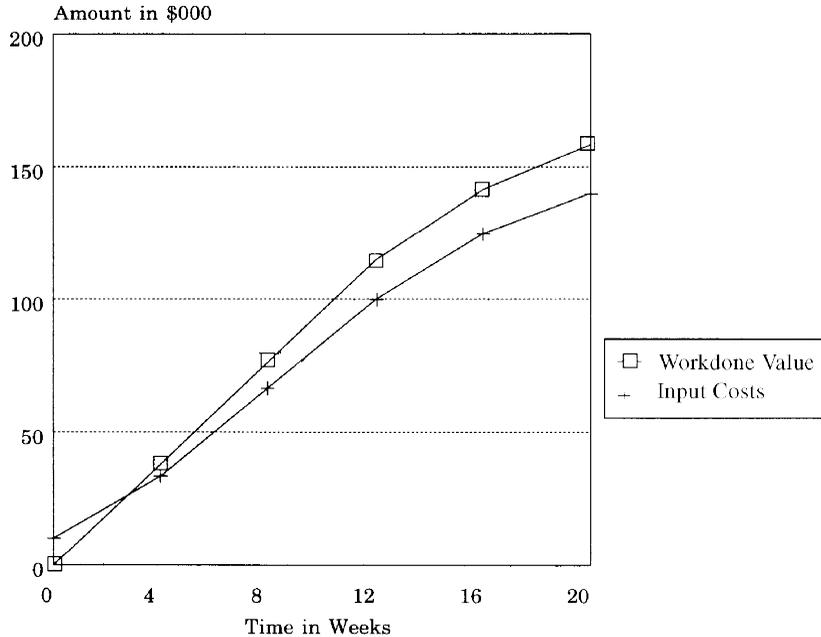
joinery, metal work tiling, painting, and other finishing items. It may be noted that the 'rate of work' forecast gives both the extent of work to be done date-wise, as well as the time period in which the work is to be executed. This forecast forms the basis for determining the physical resource forecas.t

Direct labour forecast.   It shows date-wise, the number and trade categories of workers required. It forms the basis for manpower planning and mobilisation.

Direct materials forecast.   These indicate, date-wise, the quantity of various items of major materials required. This enables formulation of the materials procurement plan and the stock-inventory.

Special-purpose plant and machinery forecast.   This is used to plan the procurement of special-purpose plant and machinery, such as earthwork machinery, concrete production, transportation and placing machinery, shuttering equipment, reinforcement fabrication machinery, and lifting and erection machinery.

Direct production costs forecast.   This shows the trend and extent the direct product costs of input resources.

Performance forecast.   Performance measures the expected output and what is produced with the actual input resources. It includes forecasts and actual quantity of work done, the resources

Table 6.10

Daily Rate of Work Forecast	Typical Items of Input Resource Requirement
Excavation in m^3	Excavators and dumpers teams
Reinforcement fixing (in tones)	Steel, fabrication machinery and steel-fixing gang
Shuttering in m^2	Shuttering materials, equipment and shuttering gangs
Concreting	Concreting materials, equipment and manpower
Pre-cast concrete erection (in nos.)	Precast elements, cranes and erection gangs
Masonry in m^2	Hollow block and masonry gang
Plastering in m^2	Materials, mortar-mixer and masonry gang

actually employed to execute the work, the production costs, the earned value of work done at contract rates, and changes in anticipated cash flow. The schedule provides the framework for evaluating performance with respect to time frame (date-wise). Forecasting of profit and cash flow is detailed in **Chapter 12**.

6.5.3 Multi-project Resources Scheduling Guidelines

A construction corporate has number of projects running concurrently. These projects may be at different locations and may have some common features like employing similar resources, material testing laboratories, and common calendar. Some projects may have different performing agencies. All these projects of a construction corporate interact with each other in their demand for vital resources and funds requirement. There can be no tailor made solutions to meet varying demands of the projects but the following guidelines can streamline the management:

- Follow similar project calendar;
- Plan each project separately and then schedule. The vital resources of each project depending upon the availability;
- Standardise BOQ items and monitoring system, as far as feasible; and
- Priorities common activities, in various projects on basis of delivery dates. Compromise in case of conflicts.

❑ 6.6 SCHEDULE HIERARCHY

The schedule hierarchy depicts the levels of various schedules in relation to each other. Each level of schedules is meant to serve the information needs of the corresponding management level.

A typical pyramidal structure of schedule hierarchy having five levels is shown in **Figure 6.9**. The characteristics associated with the various levels of schedules are given in **Table 3.1**. The pur pose of each schedule is outlined below:

Figure 6.9

Schedule Hierarchy: Project Construction Phase–Medium size Project
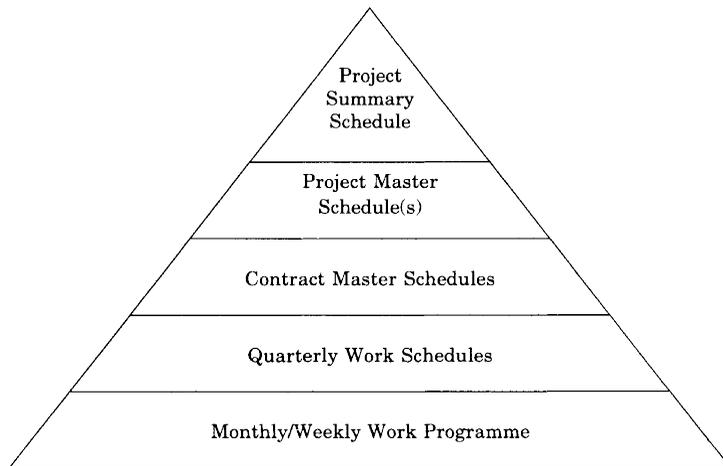
1. **Project summary schedule**. It shows the outline of the time plan for executing the project. It contains the schedule of sub-projects and tasks. The time scale unit is either taken as a month or a week. These schedules are used at the top management level to highlight the plan and progress of various project milestones.
2. **Project master schedule**. It shows the project plan for execution of work-packages and other important activities. It is the project management's plan for commencing, progressing, monitoring, and controlling work. It is prepared by integrating the schedules of sub-projects and tasks or by scheduling the project network.
3. **Contract master schedule**. A contract schedule depicts the execution plan of activities been involved in the execution of a contracted work. The contract master schedule is used to:

- Systematically control the contracted work, and
- Determine the time effect of work deviation and unforeseen circumstances.

The contract master schedule is linked up with the project master schedule and is supplemented by the respective contract's master networks:

a. *Responsibility centre work schedule*. It reflects the work programme of the responsibility centre and its scope ranges from a quarter or a month to the entire life span of the centre. It is prepared in sufficient details to enable the supervisors to plan their weekly work programme.
b. *Supervisors' work programme*. This shows the day-to-day work execution schedule of the supervisors or foremen in charge of work. These programmes are prepared on a fortnightly or weekly basis, and are detailed enough to include the operations or processes of each construction activity.

The number of levels in a schedule hierarchy is not fixed, but depends upon the nature, type, and complexity of the project. A simple project being executed by a contractor may hardly need two schedule levels, whereas, a large size complex project may require even more than five levels.

In the schedule hierarchy structure, the schedule levels are related to the management and Work Breakdown Structure levels. The consistency in this correlation can go a long way in building up an integrated master schedule for planning and monitoring the project work and providing appropriate information at the various management levels.

APPENDIX F

Project Management Software

❑ F.1 INTRODUCTION

The market is flooded with project management software. A search for project management software on the world-wide-web reveals hundreds of software solutions related to project management. Each software manufacturer claims to be the best for certain functions. MS Project is a widely used computerised project management tool but Primavera products are the most sophisticated. MS Excel is a useful tool for work-sheet analysis. Oracle-Primavera products including Primavera P6 Enterprise Project Portfolio Management (P6 EPPM), Primavera Professional Project Management (P6), Primavera Project Planner (P3), Primavera SureTrak, and many others (visit oracle.com/primavera website). Other project management software includes, MS Project 2013, Project Scheduler, Artemis Prestige, and Power Project. Readers are advised to visit the website of the concerned software companies. It may be noted that there is no single project management software that meets all the needs of all projects. The ultra high-tech sophisticated software is difficult to implement, learn, and support. The application of the project management software depends upon the level of use, types of uses, level of training received by the respondents, and adequacy of the software.

❑ F.2 PROJECT MANAGEMENT SOFTWARE SALIENT FEATURES

Primavera Project Planner (P3) to P6, EPPM and, Microsoft Project 2000 to 2007, are commonly used project management software. The main focus of P3 is on a single project; whereas, P6 is for multi-project, multi-user environments of an enterprise. The latest project management packages have most of the following features:

- Planning and Schedule Development facilities;

- Project resources and cost management facilities;
- Project monitoring facilities;
- Project data organising and filtering (sorting) facilities;
- Reporting and graphics facilities;
- Editing Facilities, Utilities and Web-enabled Applications;
- Creating many different layouts. A layout shows the view of the processed data; and
- Data and documents management facilities.

The capabilities of project management software are illustrated with 'layouts' from Primavera Software. The input data needed to assign responsibilities, develop time schedule, and forecast value of work done using Project Management software, is given in **Exhibit F.1** showing APEX Project Input Data Sheet.

Exhibit F.1

Primavera APEX Project Input Data Sheet

Activity ID	Activity Description	Orig Dur	Predecessors	Successors	RESP	Resource ID	Budgeted Quantity	Budgeted Cost	Cost Account (11)	DEPT	PHAS	Cal ID
BA400	Design Building Addition	20		BA501	MASON	DES ENG	0.00	0.00	13106	ENG	DESGN	1
AS100	Define System	10		AS101	MASON	ANALYST, ATM ENG	120.00	2,960.00	11101, 11101	ENG	DESGN	1
AS101	System Design	20	AS100	AS102, AS204,	MASON	DES ENG, ANALYST,	640.00	16,640.00	11101,	ENG	DESGN	1
AS204	Prepare Drawings for Temp	10	AS101	AS205	MASON	ATM ENG	80.00	1,760.00	11211	ENG	DESGN	1
AS216	Prepare Drawings for System	10	AS101*	AS217*	MASON	ATM ENG	80.00	1,760.00	11231	ENG	DESGN	1
BA501	Review and Approve Designs	14	BA400	BA450*,	ACME	DES ENG	56.00	1,680.00	13106	ENG	DESGN	1
AS102	Approve System Design	10	AS101	AS310*, CS300	MASON	PRG MGR, ANALYST	80.00	2,546.00	11101, 11101	ENG	DESGN	1
AS205	Review and Approve Temp	5	AS204	AS200	EVANS	ATM ENG, PRG	100.00	2,826.00	11211,	ENG	DESGN	1
AS200	Prepare and Solicit Bids for	5	AS205	AS201	FOLEY	ACCTS, ATM ENG	60.00	1,080.00	11213, 11213	PCH	PROCR	1
AS310	Site Preparation	10	AS102*	AS103*,	MILLS	FLD ENG3	40.00	680.00	11213	ISD	SYS1	1
AS240	Installation Begins	0	AS310*		MILLS		0.00	0.00		ISD	SYS1	1
BA450	Assemble Brick Samples	10	BA501*	BA530*	FOLEY		0.00	0.00		PCH	PROCR	1
BA640	Site Preparation	20	BA630*	BA650*	NOLAN	EXCAVATR	960.00	20,640.00	13206	CON	FOUND	1
BA480	Assemble and Submit	10	BA501*	BA560*	FOLEY		0.00	0.00		PCH	PROCR	1
AS202	Award Contract for Temp	1	AS201	AS206*	FOLEY	ACCTS	4.00	64.00	11213	PCH	PROCR	1

Budget	Codes	Constr	Cost	Custom	Dates	Log	Pred	Res	Succ	WBS	Help

ID BA400   Design Building Addition   Previous Next <<Less   Note: Calendar ID is 5-day/ Week

OD 20 Pct 0.0 Cal 1   ☐ ES 27SEP99 ▾   ☐ EF 22OCT99 ▾   TF: 0
RD 20 Type Task   LS 27SEP99 ▾   LF 22OCT99 ▾   FF: 0

ENG	MASON	DESGN		BADSG	AM.03.1.
Dept	Resp	Phas	Step	Item	WBS

F.2.1   Planning, Schedule Development and Organising Facilities

These include preparation of networks, activity schedule matrix, project bar chart schedule, time-scaled network, scheduling and resource leveling-manually or automatically, at the project group and/ or project level. In project management software, the processed data produces two types of layouts, i.e. Bar Chart layout and Network layout. Bar Chart layout includes Activity Data Table with a time scaled schedule displaying activity bars, whereas, a Network layout shows the logic of activities. Project management software makes it easy to organise data using common attributes,

Exhibit F.2

APEX Project: Classic Schedule Layout with Bar Chart Scheduled by Dates
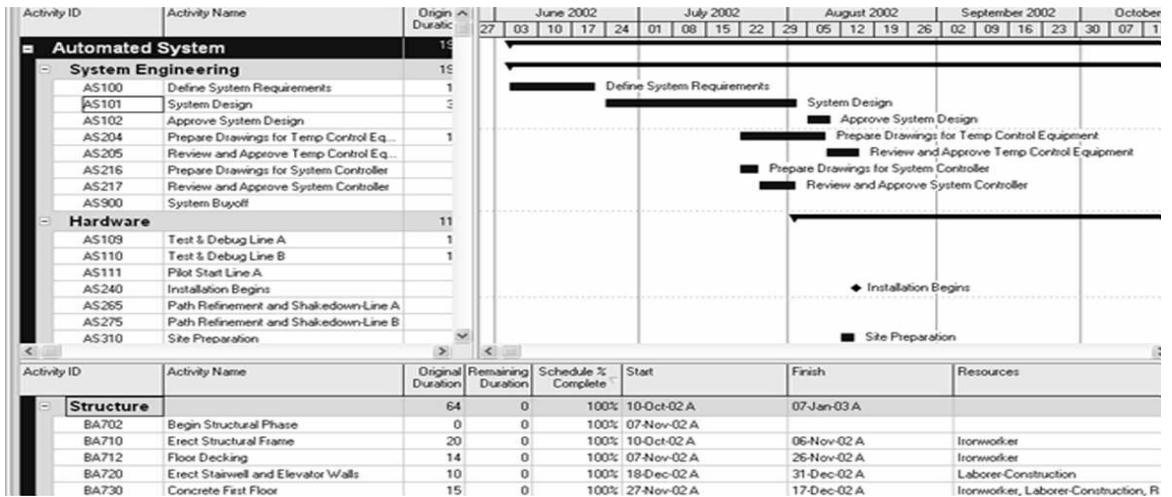
such as responsibility, phases, resources costs, calendar months, etc. The organised data is suitably titled in bands using different colors and fonts. The network plans can also be split into titled bands, such as phases and sub-networks. Project management software can handle practically unlimited activities with activity-associated characteristics such as department, responsibility, phases, locations, resources, costs, and earned value. It can classify activities in a hierarchy of work breakdown levels.

A developed plan model and schedule includes:

- Precedence diagramming method (PDM) with defined logic, lead and lag, and customised node templates;
- PDM sub-network charts with 'Trace Logic' of selected package of network and cosmic views;
- Activity data table;
- Classic bar chart with and without logical links and floats; and
- Time scale with calendar months, weeks, dates or simply serially numbered weeks.

Examples

Note: The cosmic view on the right top corner of window of **Exhibit F.3** shows activities in smaller zoom level for conceptualising and navigation.

F.2.2   Editing Facilities and Utilities

Project management software can add, modify, and delete activities. It can redefine activities, relationships, and update work progress on the screen with the help of a mouse click. The utilities provided in project management software include:

Exhibit F.3

APEX Project: PERT with Cosmic View by Phases
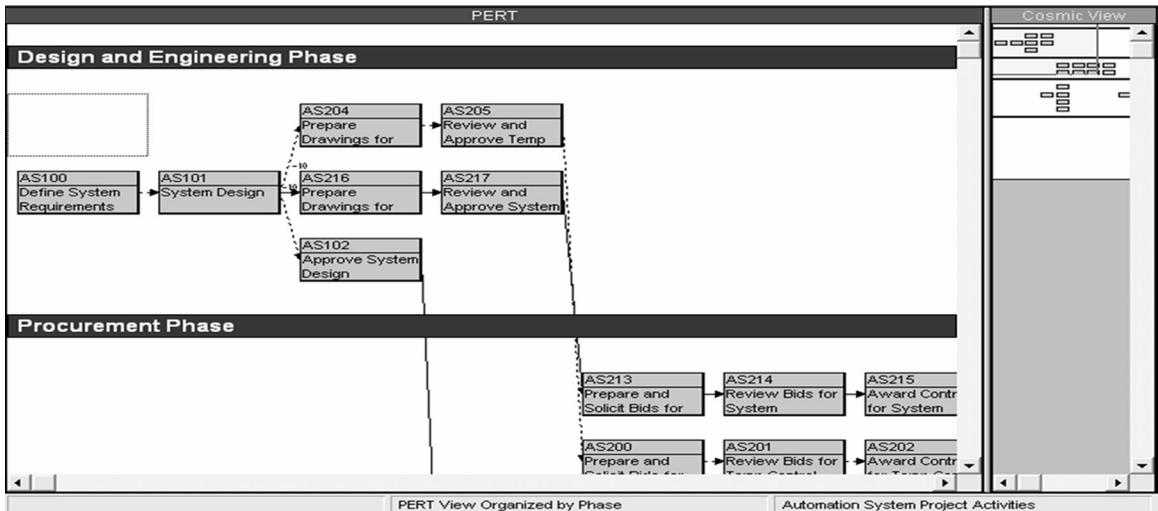
- Copy, paste, summaries, back-up, restore, import and export, merge multiple projects
- Global change feature for mass project changes
- Print-to-fit a specific size of pages
- Read/ write files
- Share data with other Project Management software
- Customise bar chart displays and network layout including adding, necking and User-definable bars, start and end points, colors, fonts, sizes and positions
- Multi-level project security on per-user basis by user names and passwords

F.2.3   Project Resources and Cost Management Facilities

Project Management software can include unlimited resources per project with activity splitting, stretching, and crunching during levelling and smoothing. Software can cater for:

- Non-linear resources usage profiles;
- Prioritisable forward and backward leveling and smoothing;
- Resources pricing and availability;
- Resource-driven activity durations;
- Earned value histograms, tables and curves;
- Unlimited cost accounts per project with intelligent many character codes; and
- Track costs and budget trend, forecasting of cash flow, actual cost-to-date, percent complete, earned value, to complete, cost at completion.

Exhibit F.4

APEX Project: Activities Details with Sub-Network
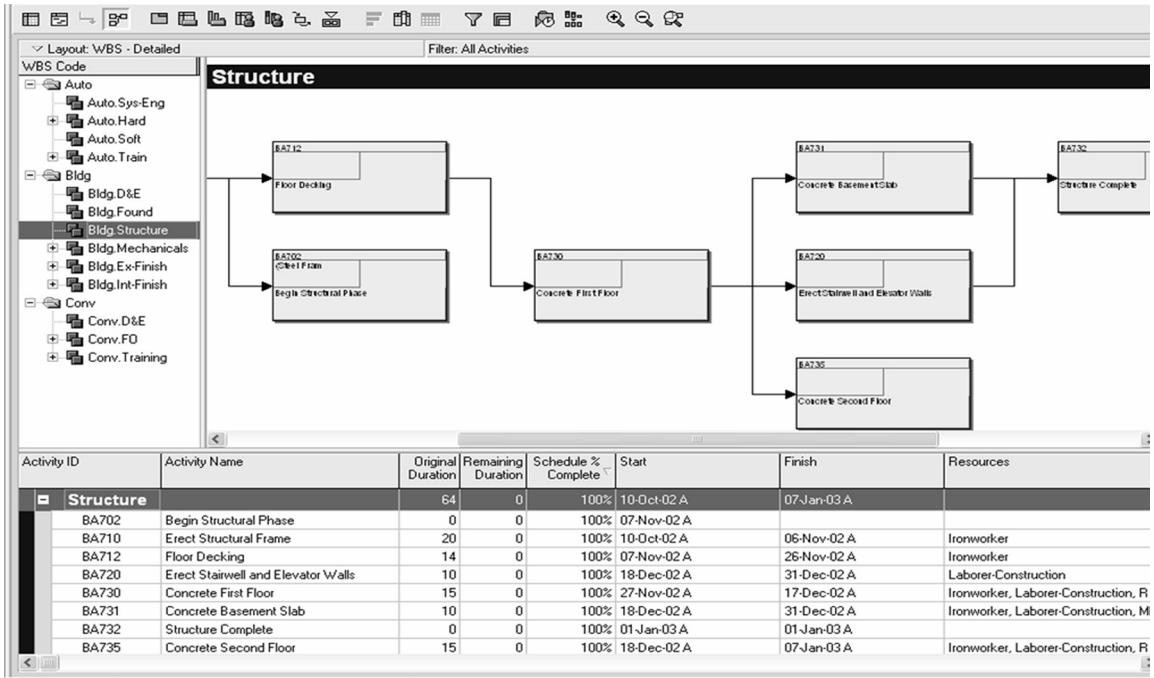
F.2.4   Project Monitoring Facilities

After updating the progress with easy to use forms, such as an activity details form and by creating an additional target plan, project management software can provide information in respect of the following:

- Changes from baseline;
- Activities scheduled in the near future (e.g. next three months);
- Revised updated schedule and network;
- What-if analysis to determine the changes needed to time compress and/or crash activities in order to complete the project within a specified time;
- Multi-project resource and task relationship;
- Implications of emerging constraints/ bottleneck.

F.2.5   Data Organisation and Filtering

Project management software organisational features enable the arrangement of activities into groups based on a common attribute, such as an activity code or the sorting of activities by total float. Activities can also be organised based on a user-defined database according to activities, resources, costs, or earned value.

Filtering activities focus on specific groups. A filter can sort projects by sub-projects and schedule in-progress activities. It can sort activities with constraints, 'near critical activities', completed activities, activities by trades, and so on. Performance reports generated by project management software include (by default) varieties of time control.

Exhibit F.5

APEX Project: Resource Profile with Curves
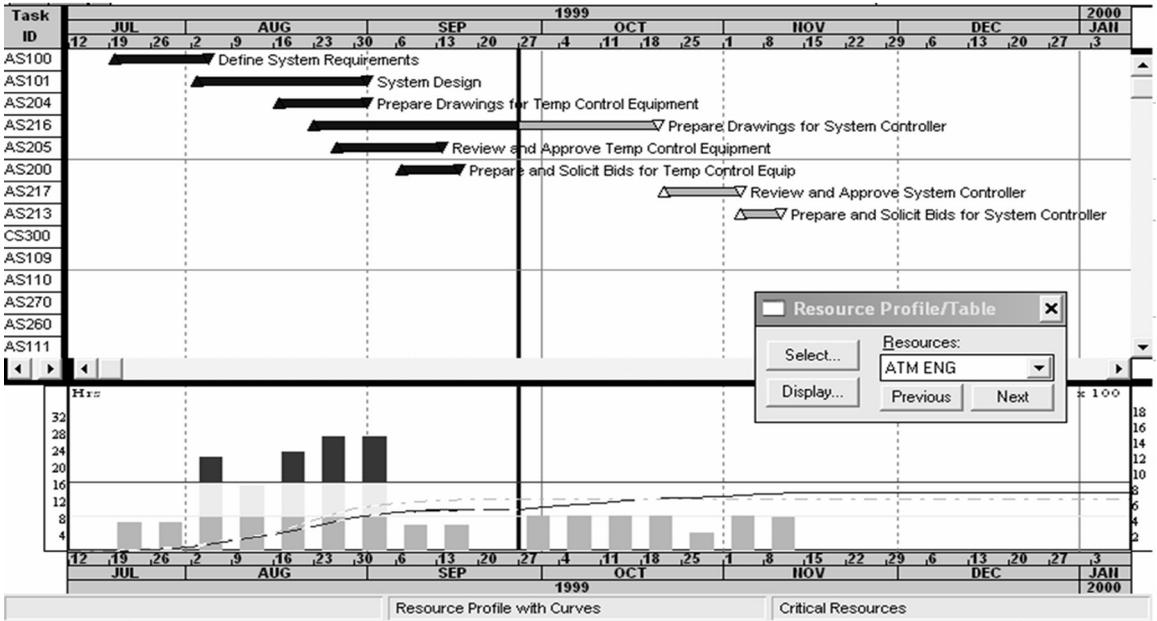
F.2.6   Reports and Graphic Facilities

Performance reports generated by project management software include varieties of time control reports; resources control reports, and cost control reports. By specifying project performance data and executing the appropriate commands, computers can be made to provide the information very quickly. What-if problems can be resolved promptly. This easy-to-read on-the-spot information can either be seen on the screen or printed, as hard copies with suitable commands to:

- Summarise group activities and compare targets;
- Pre-define tabular and matrix reports and graphics;
- Prepare unlimited presentation layouts;
- Organise hierarchical project outlining by any combination of activity codes and resources;
- Provide resource/cost histograms, tables, and curves;
- Produce reports and graphics in groups or one at a time; and

Exhibit F.6

APEX Project: Resource Table
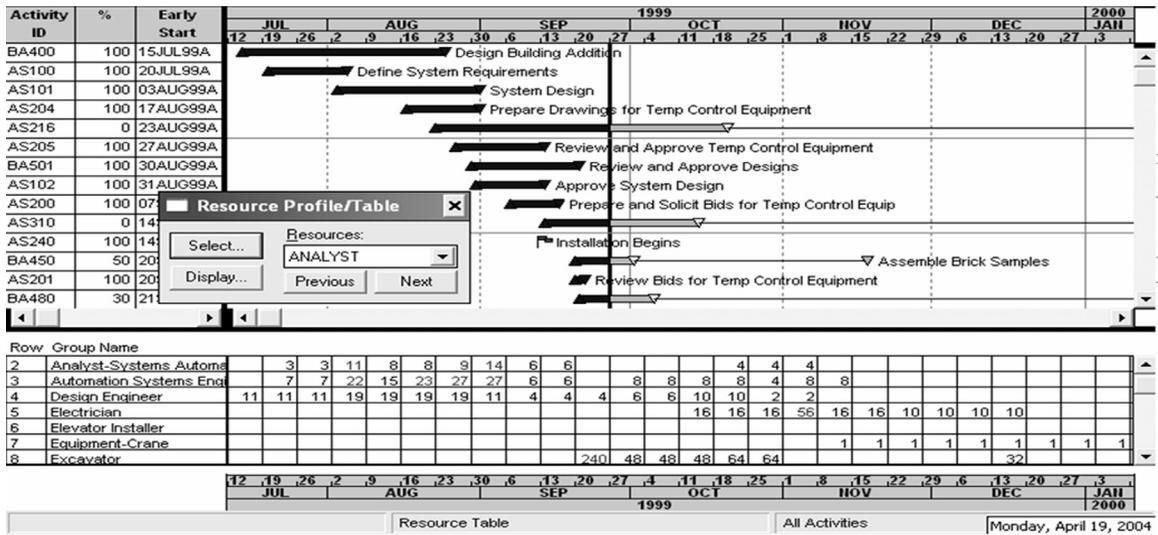
Exhibit F.7

APEX Project: Updated Schedule Layout; Group by Dept.; Resp.
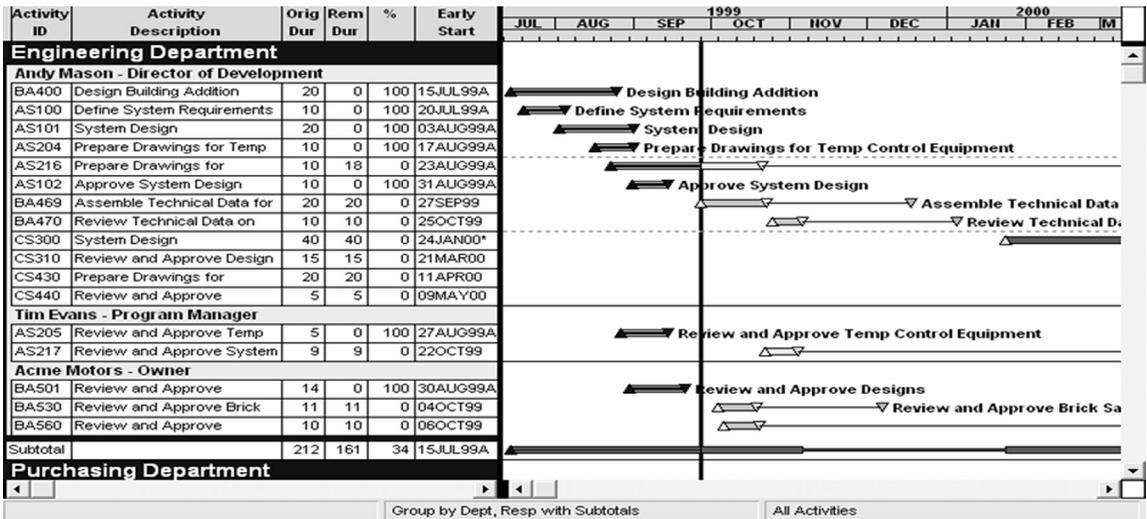
- Perform in multiple levels of sorting and selection (filter).

Most of the project management software can be communicated through internet and can import or export data with other software.

Exhibit F.8

APEX Project: Updated Sub-Networks Layout

F.2.7 Additional Operating Facilities Supported by Sophisticated Software like P6 Version 8.x

1. Multiple User/Multiple Project Access

- Multiple user access to all projects and resource data so that all project participants can get to the same project information simultaneously.
- Multiple projects can access simultaneously and view their activities information simultaneously.

2. Web based Project Management Additional Features

- Provides a common data platform and role-based tools Quick and easy updates via the web Offers a true web based project planning facility.

3. Offline Capabilities

- Detached access is possible via Primavera's check-in/check-out features.

4. Application Security

- Users only see a filtered view of their piece of the project, while allowing each team to view and update only their individual pieces, thereby, enforcing and security is enforced.

Exhibit F.9

APEX Project: Early Vs. Target Bar Chart/Titles in Bar
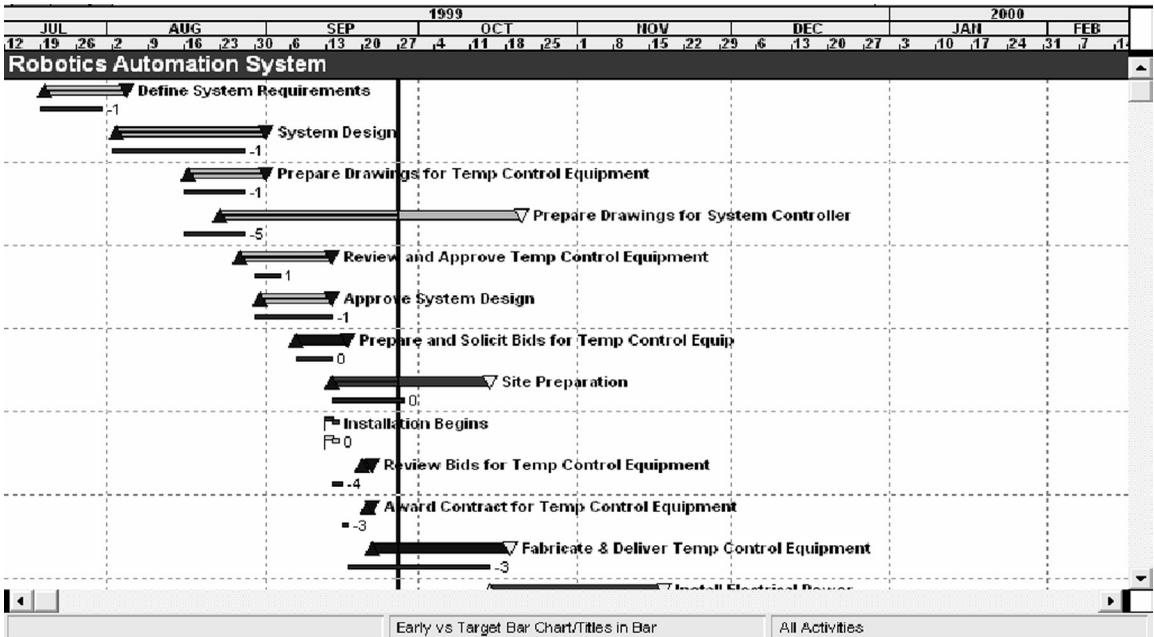
5. Additional Reporting Facilities

- Portfolio comparisons and What-if analysis from the web;
- Ability to drill down, roll up, pivot, graph key metrics; and
- Create and customise a multitude of graphical layouts and cross-project reports.

6. Document Control

- Allows for document check-in and check-out, trail of the document's edit history, storage with version roll back, and automated review and approval.

7. Risk Management

- Allows risk management facilities in collaboration with other software.

For more information on the following Oracle's Primavera products visit oracle.com/primavera.

❑ **F.3 PRIMAVERA PROJECT MANAGEMENT SOFTWARE ORACLE P6 VERS. 8. X LAYOUTS LIST**

Oracle's Primavera, one of the leaders in this field has wide range of products to help project-intensive businesses manage their entire projects of all sizes. These include:

Exhibit F.10

APEX Project: Two-Month Look Ahead with Bar Patterns
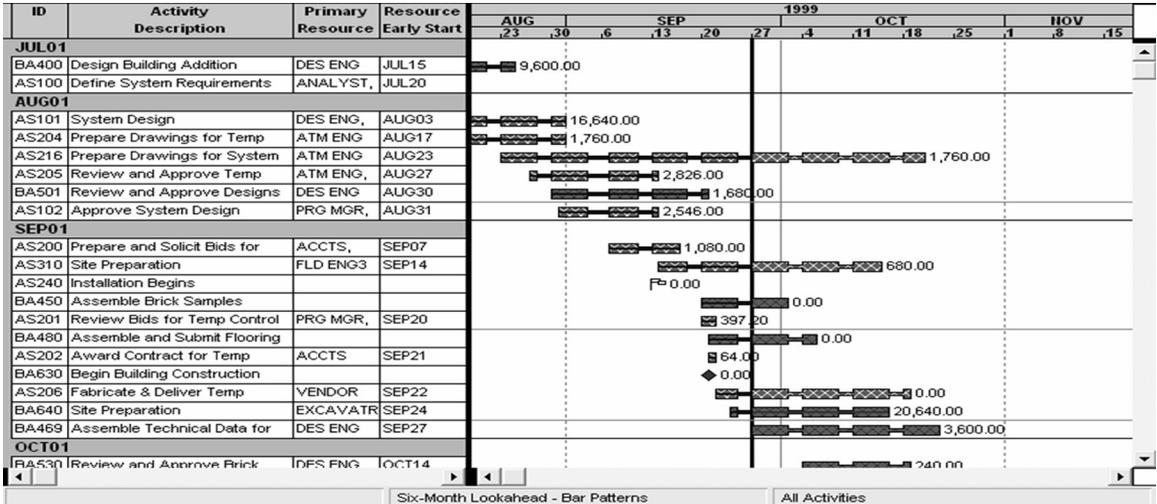
Note: Next in the Bar show non-working day period.

Exhibit F.11.

APEX Project: Filtered Near Critical Activities Layout
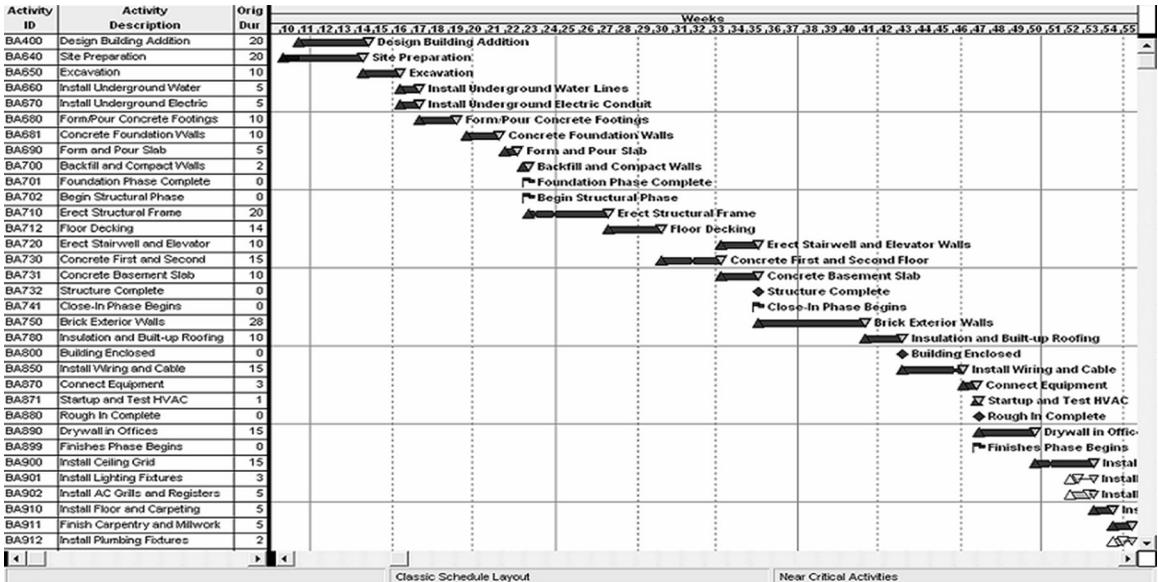
ORACLE'S Primavera Enterprise Project Management Products
Primavera P6 Enterprise Project Portfolio Management :
Primavera P6 Professional Project Management Release 7.0. and higher
Primavera Portfolio Management
Primavera Inspire for SAP
Primavera Contract Management
Primavera Risk Analysis
Primavera Earned Value Management
Primavera Contractor
Primavera SureTrak
Primavera P3 Project Planner
Primavera Integration Solutions

Primavera P6 Project Management Module (hereafter addressed as P6 Professional) is comprehensive, multi-project planning and control software, built on Oracle and Microsoft SQL Server relational databases for enterprise-wide project management stability. It can stand alone for project and resource management, or it can be used in conjunction with other products, including the Timesheet module, Portfolio Analysis Module, Methodology Management Module, and Primavera.

The Project Management Module enables your organisation to store and manage its projects in a central location (The module supports work breakdown structures (WBS), Organisational Breakdown Structure (OBS), user-defined fields and codes, critical-path-method (CPM) scheduling, and resource leveling. The following table shows the current Primavera Project Management software products:

Release	Standalone and Workgroups
P6 upto v7.0	P6 Project Management
P6 R8.x	P6 Professional (there is No. R8.0)

In P6 Professional R8.x, Methodology Management and Project Architect have been removed. The P6 EPPM R8.x is also available to cater for larger pool of users (say more than 50). The latest version that P6 Professional R8.x provides facilities to produce the following layouts for organising the output:

1. Baseline Vs. Current
2. Calendar and Ordinal Timescale
3. Classic EPS/WBS Layout
4. Classic Schedule Layout
5. Classic WBS Layout
6. Costs Analysis
7. Costs – Actual
8. Costs – Budgeted
9. Costs – Earned Value
10. Costs – Planned
11. Critical Path – Logic View
12. Earned Value – Costs
13. Earned Value – Variances
14. Earned Value Analysis

15. Float Path Layout
16. Future Period Planning
17. Gantt Chart
18. Past Period Actual for Labour Layout
19. Predecessor/Successor Analysis
20. Resource Availability Spreadsheet
21. Resource Cost Spreadsheet
22. Resource Over Allocation Profile
23. Resource Units Profile
24. Resource Units Spreadsheet
25. Resource – Allocated Limits
26. Standard Activity Status
27. Workload Analysi

Planning Project Site Construction Manpower

An organisation enables a group of people working together with their respective tasks and responsibilities, to co-ordinate their activities smoothly, in order to achieve a common goal. A traditional formal organisation (form and structure) integrates its various components by assigning tasks to individuals, defining lines of authority and responsibility through hierarchical levels, and formalising authority, responsibility and accountability, and reporting relationship. Traditionally, the operational unit organisations are based on certain classical principles, such as Unity of Command, Scalar Chain of Command, the Division of Labour, and the Span of Control. Excessive reliance on the 'principles' of organisations can lead to over-centralisation, curbed initiative, unnecessary bureaucratic controls, delays, and interference in management. It also neglects the 'human' factor, as the people are integrated into the organisation more by regulation as compared to commitment. The rapid growth of technology and demand for cheaper, better, and faster delivery of new facilities, has led to new thinking towards restructuring, downsizing, and empowerment of organisations. Project site organisation is a result of this new evolutionary process.

Being a critical resource, manpower is of great concern during development of project organisation. Manpower planning covers project administration manpower and direct and indirect manpower. The planning of direct workers in project construction is primarily concerned with estimating the workers' productivity, scheduling manpower employment, and structuring it into workers' teams and work-groups, with a view to economically match manpower supply with that of task's requirements. The various functions performed by the project planning team with respect to manpower planning are listed in **Table 7.1**.

The scope of project organisation and construction manpower planning, covered in this chapter is restricted to the following sections:

1. Structuring Construction Site Operational Units
2. Classifying Construction Site Workers
3. Estimating Direct Workers of an Activity

4. Scheduling and Grouping of Construction Site Manpower
5. Organising Project Manpower into Responsibility Centres

Table 7.1

Project Planning Team: Typical Manpower Planning Functions

1.	Determining expected labour productivity;
2.	Estimating workers requirement for each work package;
3.	Scheduling date-wise, category-wise, project direct labour;
4.	Establishing a construction teams;
5.	Organising task forces;
6.	Allocating labour during execution stage;
7.	Monitoring workers productivity at site;
8.	Recording productivity data:
9.	Costing and controlling manpower costs:
10.	Controlling manpower mobilisation, distribution and demobilisation;
11.	Defining job requirement for key executive and staff appointments;
12.	Assist in recruitment of personnel;
13.	Assist in designing incentive system;
14.	Assist in controlling manpower costs; and
15.	Assist in training and induction of manpower.

This chapter excludes indirect manpower that is needed for administration, which varies from site to site. The workers' productivity control methodology is described in **Chapter 14**. The incentive scheme for civil works with output norms of Indian construction workers, which was implemented by the author in a construction corporate in UAE is outlined in **Appendix G**.

❑ 7.1 STRUCTURING CONSTRUCTION SITE OPERATIONAL UNITS

7.1.1 Project Outline Organisation

The rapid growth of technology and demand for cheaper, better, and faster delivery of new productshas led to new thinking towards restructuring, downsizing, and empowerment of organisations. The emerging scenario is to have flat and lean organisations, which will perform efficiently and effectively within the constantly changing environment, and will be cost effective in terms of human resources. Project organisation is a result of this new evolutionary process.

To quote an example, the organisational structure of a housing construction project, is shown in **Exhibit 7.1** and its scope of work is outlined in **Table 3.3** of **Section 3.1.3.** The project management organisational form and structuring of site operational responsibility centres,, in each project, should be customised.

Exhibit 7.1

Housing Project Site Organisation Structure

Project Organisation

```
                              Project
                               Chief
              ┌──────────────────┴──────────────────┐
            Staff                                  Line
   Technical and                            Site Execution
   Administration                                   │
      Support                              Quality Control/
                                               Safety
```

Staff side (Technical and Administration Support):
- Technical Management
- Material Management
- Personnel Management
- Planning & Monitoring
- Contract Administration
- Finance Management

Line side (Site Execution):
- Foundation
- Finishes of Buildings
- Mechanical/ Maintenance Workshop
- Super-structure
- External Services
- Manufacture/ Fabrication Management

7.1.2   Project Site Organisational form Requirements

Construction site organisation differs from that of traditional organisation. A project is organised in order to achieve its mission, within pre-determined objectives and is temporary. Project organisation is conceived during the project initiation stage and it comes into existence prior to the start of the planning stage following a gradual growth. It also undergoes changes during various stages of the project life cycle in order to meet project needs. Towards the end, it runs down and ceases. after project's completion . The project organisation requirements include:

- Innovation to overcome problems as they arise;
- Experience to make sound and efficient decisions;
- Rapid response to changing situations; and
- Effective control of project specified purpose and time, cost and quality objectives.

   Its special attributes include its innovation capacity to overcome crisis/problems. It is staffed with experienced people to respond speedily to changing situation leading to speed up decision making. Its accomplishment is entrusted to a single person—the project manager, who acts as a single point of accountability.

   The success of a project to a great extent relies on its organisational form that supports the project requirements efficiently and economically. The matrix organisation form, suitably designed (**Section 1.7.2**), is generally adopted for the form of project organisation.

7.1.3   Structure of Operating Units

Project objectives are linked with the performance of a number of result oriented organisational units. These units are structured according to their task responsibility reporting relationship as can be seen in **Exhibit 7.2**, depicting the organisational chart of the housing units project.

   The number of organisational units depend on the magnitude and complexity of the project. A simple project may have only a few organisational units, whereas, a large number of interacting organisational units are required for a large and complex project. In a major project, each organisational unit is usually headed by a manager and is referred to as a responsibility centre.

7.1.4   The Classical Management Organisational Principles and Their Limitations in Structuring Site Operational Units

Classical Organisational Principles.   An organisational structure refers to authority configuration that is been given to a body of people for providing direction. Traditionally, structure are based on classic organisation principles outlines, described as follows:

1   *Unity of objective*. An organisation structure is sound when it facilitates the accomplishment of objectives. Therefore; the organisation as a whole and every part of it must be geared to the basic objectives of the enterprise.

Exhibit 7.2

2000 Housing Units Project Responsibility Centres

Project Management Responsibility Centres Organisation

Construction Responsibility Centres

- Building Foundation Centre
- Building Finishes Centre
- Precast Erection Centre
- Public Building Centre
- Pavement Construction Centre
- Landscaping Centre

Services Responsibility Centres

- Pre-cast Concrete Production Factory
- Readymix Concrete Production Plant
- Steel Fabrication Shop
- Quarrying Establishment
- Plant & Machinery Maintenance Unit

Management and Administration Responsibility Centres

- Administration & Personal Management
- Materials Management
- Plant & Machinery Management
- Finance Management
- Cost Management
- Engineering Services Management
- Contract Management
- Planning and Monitoring Cell

2. *Specialisation of division of work*. The activities of each member of the organisation should be confined, as far as possible, to the performance of a single function.
3. *Span of control*. Each manager should have a limited number of sub-ordinates reporting to him directly. Generally, the span should be narrow for complex work; while, it should be wide for simple and routine work. However, the span should be neither too wide nor too narrow. The span of control depends upon many factors such as:
   - Nature of work;
   - Project characteristics, including execution times;
   - Moral and competence of the people;
   - Capability of the leaders at various levels; and

- Management policy regarding decentralisation, information system and the degree of control.

4. *Scalar principle*. There should be a clear chain of commands , which are running from the top to the bottom of the organisation. Each sub-ordinate should know about his superior as well as his sub-ordinates.

5. *Functional definition*. Duties on functions, authority, and responsibility for each position should be clearly defined to avoid duplication of work and overlapping of functions.

6. Exception principle. Only exceptional matters; which are beyond the authority of persons at the lower level should be referred as higher levels. Routine matters should be dealt by executives at lower levels.

7. *Unity of command*. Each sub-ordinate should have only one superior, whose command is to be obeyed. This is necessary to ensure discipline and to fix responsibility for obtaining results.

8. Balance. A proper balance should be maintained between centralisation and de-centralisation. Each function in the organisation should be developed to the point at which the value received is at least equal to the costs.

9. *Efficiency*. The organisational structure should facilitate the achievement of objectives at the minimum possible cost. It should permit the optimum use of resources.

10. *Flexibility*. The organisational structure should be sufficiently adaptable so as to accommodate technical and other changes in the environment. Therefore; complicated procedures, red tape and complexity of control should be avoided. At the same time, the organisational structure should be reasonably stable to withstand changes.

11. *Continuity*. Proper arrangements should be made for the training and development of executives and workers.

12. *Facilitation of Leadership*. The organisational structure should be devised so that there is sufficient opportunity for the management to provide effective enterprise leadership .

13. *Parity of Authority and Responsibility*. In every position, the authority and responsibility should be adhered. Adequate authority should be delegated at all levels and wherever, authority is delegated, the person at that level should be held responsible.

14. *Co-ordination*. The organisational structure should facilitate unity of effort or co-ordination among different individuals and groups. Channels of communication should be open and clear.

Limitations of Classical Organisational Principles in Structuring Units. Classical organisations are based on certain principles, which may not be relevant today, in project organisation. The emphasis on unity of command was based on having one superior, for each, person or group. The new trend is towards a multiple command system. Scalar Chain of Command laid emphasis on the vertical hierarchy that is a concept, which is too rigid and is not imperative in today's environment. The Span of Control Theory limits the span of control of a supervisor to maximum number of workers. This is changing with the application of information technology, communication skills, and improvement in educational standards at all levels.

Once created, organisations were considered as closed systems. This is a major flaw in the theory and in the current scenario they have many limitations. This is due to the fact that gnerally an organisation cannot remain static or retain universality under all conditions.

Classical chains of hierarchies tend to be bureaucratic and inflexible. Bureaucratic controls and excessive reliance on the principles of organisation can lead to over-centralisation; curbing initiative, delays in decision-making, and interference in management. It is difficult for the frontline operating units or organisational components to interact in bureaucratic hierarchies, in both, vertically as well as horizontally. Formal structures create barriers to innovation particularly in the front-line operating units, where human factor is neglected. People are integrated into the classical organisation pattern more by regulation, than, by commitment.

7.1.5   Operating Units Organisation Guidelines

There are no tailor-made project organisational forms and structures to meet all situations in all projects since no two projects are similar. Organisational forms and structures are dictated by many parameters. These parameters include project size, objectives, people relationship, technology, complexity , administrative component, specialisation, span of control, need for delegation, decision levels, organisation culture, and the emotional stability of the people. Therefore, structural design of project site operational units in each project needs to be customised.

The guidelines for designing the organisational structure of the projects operational units include the following:

1. Organisational groups are designed to generally conform to the project Work Breakdown Structure.
2. Each group is assigned responsibilities and allocated resources to meet the assigned tasks.
3. The size and structure of the organisation is changed due to alteration in requirements. However, the core project team continues till the end.
4. Project groups are suitably structured with emphasis on team-work and informal relationship.
5. Organisational structure is kept flat to avoid bureaucratic tendencies and reduce channels of communication with the project manager.

❑ 7.2   CLASSIFYING CONSTRUCTION SITE WORKERS

Workers at the project site are made to perform a specified function and its connected tasks. These workers include supervisors, construction workers, operators and drivers, and administrative personnel. For ease of estimating, planning, accounting, and controlling; the project workers are classified based on trade-wise. Further, these are divided into two groups, namely, direct workers and indirect workers.

7.2.1   Workers Trade Classifications

Construction involves multi-skill technology for its wide range of related activities. These skills vary with nature of job, type of project, and corporate policy of the contractor. The first step towards determining productivity standard is to identify the trade workers that are needed for category-wise project execution. A typical trade categorisation of construction workers encountered in a building project is shown in **Table 7.2.**

Table 7.2

Building Construction Workers Trade Classification

Building Trades	*Electrical Works*	**Drivers and Operators**
		Light vehicle drivers
Carpentry Work	Electrician	Heavy vehicle drivers
Shuttering carpenter	Cable jointer	Equipment operators
Furniture carpenter	Cable layer	**Administration Staff**
Wood polisher	Electrical helper	Office helper
Carpenter helper	*Plumbing and Sanitary Works*	Medical helper
Masonry Work	Plumber	Security staff
Concrete mason	Pipe fitter	Store keeper
Blockwork and plaster mason	Plumber helper	Cook
Tiling mason	*Unskilled Work*	Mess helper
Marble mason	*Mechanical Trades*	General helpers
Mason helper	Fitter	Janitor
RCC Steel Workt	Machinist	Tailor
Rebar fabricator	Welder	Laundry man
Rebar helper	AC mechanic	General helpers
Painting Work	Sheet fabricator	
Painter	Auto electrician	
Painter helper	Diesel mechanic	
	Petrol mechanic	
	Mechanic helper	
	Riggers	

10302: 1982, Indian Standards on 'Unified nomenclature of workmen for civil engineering', , includes around 95 categories of labours. The trade categories and crew sizes used for determining construction output also varies with various agencies publishing output planning norms. On the whole, for a given project, nomenclature of the trade categories that is needed for workers planning, mobilising, and monitoring productivity, should be identified and standardised. For planning and accounting purposes, the workers; trade-wise, are grouped into direct and indirect workers.

7.2.2 Direct Manpower

These are construction site workers who can be identified with execution of the client's permanent works, listed in the bill of quantities. The direct manpower, constitutes 70%–85% of the total manpower, which is employed at the project site.

The direct construction workers include foremen and tradesmen, skilled in various engineering trades, in addition to the semi-skilled and unskilled manpower. The tradesmen include, shuttering

carpenters, fabricators, steel fixers or iron workers, masons, plumbers, electricians, furniture carpenters, metal workers, painters, and decorators.

Generally, the wages of construction site workers are accounted on a daily or monthly basis, while, their activity-wise requirement is computed using the workers' productivity standards.

7.2.3   Indirect Manpower

The indirect manpower covers all supervisors, staff and workers, other than those coming in the direct manpower. It is required to support the direct manpower, both, technically and administratively. It generally consists of the project management and administration group.

The indirect manpower is generally accounted on monthly basis with some exceptions like special-purpose plant and machinery operators,, who can be accounted on daily wages like direct manpower. Most of the indirect manpower can be assessed during formulation of work organisation and can also be estimated using thumb-rules, which are based on experience. Classification of Indirect Manpower is detailed in **Chapter 11**.

7.2.4   Examples of Direct and Indirect Site Workers

Following are some examples of direct and indirect construction site workers:

a.   A shuttering carpenter employed in the preparation of formwork during roof construction of the building slab, which forms a part of the contract, is categorised as a direct worker, while, another carpenter who is engaged in the construction of a workers' camp (temporary accommodation) for housing labour is accounted as an indirect worker. Similarly, a welder employed in the manufacture of metallic inserts for fixing in the ground slab of a permanent building is a direct worker, while a welder in the vehicle and plant maintenance and repair workshop is considered an indirect worker.

b.   A vehicle driver of a concrete truck mixer, which is used for transporting ready-mix concrete from site batching plant and the concreting site is classified as direct worker , whereas, a driver of a personnel-carrying vehicle is taken as an indirect worker.

c.   Generally, all persons in a project those are engaged in the administrative duties, such as office functioning, supervision, repair and maintenance workshop, and operation and maintenance of utility services, are grouped as indirect workers.

❑ 7.3   ESTIMATING DIRECT WORKERS OF AN ACTIVITY

7.3.1   Developing Worker's Production Norms Approach

The basic equation for determining the workers that are required for accomplishing a specific activity or work-item is given by:

$$\text{Workers' production standard} = \text{Worker output norms} \\ \times \text{Production efficiency factor}$$

$$\text{Workers required} = \text{Work quantity}$$
$$\times \text{Workers'production standard/Completion period}$$

In the basic equation for determining workers, the quantity of work needs to be performed can be accurately estimated from the construction drawings and specifications. If the work is to be completed within the stipulated period, the variable in assessment of workers' requirement is the production standard.

Notes :

1. Workers' production standard is defined as the effort in man-days or man-hours that are needed for accomplishing a unit quantity of work, while, working efficiently but allowing for normal delays and wastage. Some expert state effort as in terms of quantity of work done per man-days or man-hours.
2. Work quantity of the activity involved is expressed in standard work units. In India, methods of measurements of Building and Civil Engineering Works is specified in BIS 1992 (28 Parts).
3. Completion period is taken as working days or hours planned or earmarked to accomplish the task.
4. Workers' production norms in the above equation, are expressed in man-days or man-hours, category-wise, which are required for accomplishing the unit work.
5. Production efficiency factor is the multiplier that is used to convert production norms into productivity standards, which are expected under job conditions at the site.

After the workers' skill are identified, the quantity of work is measured activity-wise, where activity completion time is stipulated; the estimation of direct workers involve the following steps:

- Develop workers production planning norms; and
- Determine workers production planning standard.

The computation method of direct workers' requirement as outlined above, may appear simple, but in actual practice, assessment of production efficiency and workers' productivity standards are the most challenging tasks, which are faced by the project planners.

7.3.2   Developing Workers' Production Planning Norms

The workers' production planning norms (or planning data) indicate the extent of effort that are required in terms of man-days (or man-hours) to accomplish a unit quantity of specified work or activity. These norms are sometimes referred to as 'workers production norms'. Some express the effort, in direct man-days of workers (category-wise), which can be identified with the execution of unit work or an activity. They do not comprise either indirect supporting or administrative personnel. Experienced estimators and planners compile the workers' production planning norms for estimating the man-power requirements. In the absence of such data planning, appropriate norms can be evolved using one or a combination of the following methods:

- Analysing the past similar project performance data;

- Abstracting data from published norms; and
- Work-studying the actual work process.

Analysing past similar project performance data.   The long-standing construction firms compile their basic production norms by analysing the past performance data of similar work, with the help of statistical techniques. This analysis for each item of work is carried out by statistically taking the average of the historical data for achieved output. To illustrate, the workers productivity norms used by a construction company in the Middle East for estimating and planning their building construction activities, are given in **Appendix G**.

Another example of the category and number of workers actually employed at equipment installations in a highway project is given below for guidence:

Example.   Consider a task involving 160 m² of fixing timber formwork for the roof slab of a single storey building. The time earmarked for completion is four days, working eight hours per day. If a workers' team consisting of two skilled workers and an unskilled worker can install the fair-face formwork at the rate of 1.25 m² per team hour, then:

$$\text{Effort required} = \frac{\text{Formwork quantity}}{\text{Output per team}}$$

$$= \frac{160 \text{ m}^2}{1.25 \text{ m}^2 \text{ per team-hours}}$$

$$= 128 \text{ team-hours}$$

$$\text{Team required} = \frac{\text{Team-hours}}{4 \text{ days completion period}}$$

$$= \frac{128}{4 \times 8}$$

$$= 4 \text{ Team, each of (2 skilled + 1 unskilled) tradesman}$$

$$\text{Workers required} \quad = 4 \ (2 \text{ skilled} + 1 \text{ unskilled})$$
$$= 8 \text{ skilled} + 4 \text{ unskilled.}$$

Note: The past performance data for evaluating workers' production norms has certain drawbacks as well. These drawbacks, outlined below, should be studied carefully, prior finalisation of workers productivity norms.

a. No two projects are exactly similar, and therefore; the past performance data of various projects have to be critically examined for their suitability, while, determining the norms for a given project.

b. The construction production output is constantly improving over time because of introducing better techniques and latest equipment. The analysis of past performance, therefore; may not conform to the state-of-the-art.

c. Analysis of past data is useful only, if, available data is reliable. The degree of reliability of such data needs to the ascertained prior to analysis.
d. The past analysis must not blindly include the inefficiencies or problems of the past. The actual context in which the past performance data was recorded should be studied. Moreover, the data of inefficient or problematic working periods should be discarded prior to processing.

Published production norms. A planner can derive production norms for a project by relating them with the published production norms or construction cost index of professional institutions, like the Construction Industry Development Council. Institute of Quantity Surveyors, the Builders' Associations, and other corporate and practicing bodies. For example, the Bureau of Indian Standards has published 1.8.7272 (*Part* 1): 1974, containing 'recommendations for labour output constants for building work: Part 1, North'.

Workstudy construction process.   Workstudy, uses the method of study and time techniques to find the optimum method of production with specified resources, in addition to time required for performing the production tasks, so as to establish production norms of workers and production capacity of a machine. It is a specialised field, hence, workstudy is carried out by professionals.

Some studies of construction activity shows that a workman devotes only 40%–60% of his time in the actual execution of work, with the rest spent on wasteful and unproductive activities like waiting, travelling, and personal breaks. The method study aims to find an optimum execution method of work by minimising all wasteful and unproductive activities. In this, purpose of the study is defined, method of execution is recorded, sequence of work and employed resources are critically examined, and areas of inefficiency are identified with the aim of reducing wastage.

The concept of workstudy has found wide acceptance in manufacturing industries, but in the construction field it is not so effective, as each project has unique tasks, which are affected by varying situations. The workstudy trained planners and supervisors, during the execution stage, can achieve better site productivity , but at the planning stage, off-the-job workstudy has only limited value.

7.3.3   Factors Affecting Production Efficiency and Determining Worker's Production Standards

Workers' production standard = Worker output norms × production efficiency factor

The computation of production efficiency factors depend upon numerous variable, which affect workers' productivity in actual job conditions at the project site. These variables may vary from project to project and over place and time. Some of the typical factors affecting the work production efficiency are given in the following paragraphs. The values, for change in productivity rate or human effort are indicated for conceptual purposes; these should be considered as guidelines and not mathematical rules.

Work region productivity index.   The workers' productivity norms vary from area to area. Workers coming from different areas, even when employed on a similar job, have different produc-

tivity. This difference is due to blend of numerous ethnic and environmental factors. Considering the production norms of one of these areas (or a project) as the base, the production norms for other areas can be assessed using a relative published index or experiences, as illustrated below:

Area Location	Relative Productivity Index
Zone A	0.95
Zone B	1.00
Zone C	0.93
Zone D	0.91
Zone E	0.95
Zone F	1.10

Work complexity.   A simple, familiar work, is, easier to execute than an unfamiliar, complex one. The extra effort needed for the latter type of work, specially in the initial stages, may range from 10-100% of the normal expected productivity.

Repetition of work.   While, the first-time execution of an unfamiliar work needs extra effort and results in low output, the skill acquired in the process, when utilised over a period of time to execute similar works, improves productivity rate, especially when crew of workers is the same. This improvement in production rate continues till a certain limit is reached.

This limit corresponds to the stage when the crew acquires the necessary skill and becomes thoroughly aware with the process, and the work is performed at its peak production rate. This impact of repetitive work on the production rate varies with time, nature of task, and the characteristics of the crew. As a thumb rule, the improvement in production rate can be taken from 5% to 15% for repeated work, from its initially assessed rate of about 60%–80% of the average output rate till it reaches about 120% of the average rate.

Quality control.   Stringent quality control in sensitive projects, such as in the construction of a nuclear reactor involves frequent inspections, which involve elaborate documentation and is a time consuming task. They increase the non-productive time of workers, and, in turn, reduces production by 10%–25%.

Equipment-intensive tasks.   The construction tasks which can be performed wholly or partly with equipments include, excavating, handling, transporting, filling, compaction, grading, hoisting, fabricating, precasting, erecting, plastering, finishing, paving, trenching, cable-laying, pipe-laying, and so on. Generally, special-purpose equipments are required for performing these tasks.

The construction equipment can execute work speedily, but it needs operators. The production of this man-machine combination depends upon many factors, which are covered in Chapters 9 and 10. However, the equipment-intensive tasks are less susceptible to production changes than the labour-intensive ones. The workers required for typical equipment installations are indicated as guidelines in **Table 7.3.**

Table 7.3

Workers Employed Equipment Installations

S. No.	Item	RMC 30 M³/hr	Crusher 200 TPH	Hot Mix Plant 120 TPH	Wet Mix Plant	E/M Workshop
1	Manager (Mech.)	1	1			1
2	Manager (Elect)	1	1			1
3	Dy. Manager (Incharge)	1	1			2
4	Mech. Engineer	1	1	1	1	3
5	Elect. Engineer	1	1	1		1
6	Jr. Engineer (Mech.)	1	1	1		4
7	Jr. Engineer (Elect.)	1	1	1		2
8	Supervisor	1		1	2	3
9	Sr. Foreman (M)	1	1		2	2
10	Sr. Foreman (E)	1				1
11	Jr. Foreman (M)	1	1	1	2	2
12	Jr. Foreman (E)	1	1	1		2
13	Plant Operator	1	1	1	1	1
14	Mechanic	1			1	6
15	Auto Elect.					2
16	Jr. Mechanic					8
17	Electrician	1	1	1		4
18	Welder	2				2
19	Fitter					1
20	Tyre Man					2
21	Skilled Workers	4	6	6	2	
22	Helpers	8	8	8	8	10
23	Drivers				8	4

Supervision.   A supervisor manages his assigned technical work, as well as, the workers under him. The accomplishment of tasks economically and on schedule mostly depends upon the competence of the supervisor, which in turn affects the workers' production. An efficient and effective supervisor can get a higher production from workers by reducing non-productive time.

Climatic and weather conditions. Generally, under average weather conditions with temperature varying from 20°C–30°C and relative humidity of 60%, the Indian workers continue working at the same production level. But extreme weather situations and seasonal changes, like, extreme hot or cold climate, high humidity, strong winds and rains, and working in high altitude areas, affect both production as well as the work performance.

Since construction projects are spread over several months or even years, it is necessary to adjust the effect of seasonal weather changes on workers' production as well as work execution. This adjustment in production can best assessed by working experience.

Labour availability. The labour production also depends upon the employment opportunities available in the market. If jobs are plenty and labour is scarce, the labour production tends to become less. During a slump in the construction market, labour is easily available, while, there is a scarcity of jobs. In such situations, employers can afford to be selective as hiring and firing of workers become easy. In scarce job situation, the overall production improves, since the employers can then sort out labour with a less production.There is also a tendency among labour to move to high-value large-sized projects ,since they offer them longer service, better job opportunities, and even more stability.

Role of management. The project management has a key role to play in planning and controlling production. It is responsible for, specifying the weekly work target , which is to be accomplished, by the workers as well as how the work need to be executed. During the execution stage, the management, provides necessary resource support and closely monitors the performance. Each week, it compares the planned target with the work accomplished, evaluates variances, analyses causes for variances, and takes corrective measures.

It provides feedback to the workers on their past performance and communicates performance improvement measures. It suitably rewards the workers, who have done exceptionally well, and keeps the morale of the work force high. The production is bound to suffer, if, the management fails to fulfill its role and obligations effectively.

Determining production efficiency factor. There is no single or exact method to determine production efficiency factor as there are too many factors involved, and, it is neither feasible nor desirable to evaluate the effect of all such factors that are responsible for affecting production efficiency. At the planning stage, a project planner or estimator cannot take care of all the controllable and enforceable factors. It is possible that some of these may have been considered while establishing the basic production norms. Further, it is not necessary to consider the effect of all the factors, while, modifying basic norms as some of these may overlap. However, few factors may have only a marginal effect on overall production. It is better to limit the adjustment computation in production, ranging from four to six prominent factors, which contribute significantly to overall production, and omit other factors. By using his experience and skill, the planner identifies the main factors that affect production, evaluates their implications, and finally transforms the basic production norms into standards of workers production conforming to the characteristics of the project under consideration.

Another approach to evaluate the main factors that influence workers production efficiency is to divide the production efficiency range into three basic ranges corresponding to 'low', 'average', and 'high' production conditions. The low condition ranges from 40% to 60% efficiency; average condition from 60% to 80%; and high condition from 80% to 100%.

Each major factor affecting efficiency is then evaluated considering scale of 100 at the site conditions. This evaluation, for a typical project, is given below:

Production Elements	Efficiency (%)
Nature and region of work	75
Supervision	90
Labour market	80
Climate and working conditions	60
Equipment orientation	50
Average	**71%**

The average production efficiency (355/5) is 71.0% of the basic production norms. The standard production for each work item is then obtained by multiplying the basic norms with the evaluated average production efficiency factor of the work process. However, this structured approach only provides guidelines and its outcome can best be taken as an approximate that should be further scrutinised by the planners and construction engineers.

The workers' production data used in the initial stages of the planning process may not necessarily be the workers' production standards that are used for controlling workers' performance. During the execution stage, the initially assessed production is subjected to further reviews, if necessary.

❑ 7.4 SCHEDULING CONSTRUCTION SITE WORKERS

The workers' scheduling methodology involves the following two steps:

7.4.1 Scheduling Direct Workers

The project direct manpower constitutes a major portion of the labour strength. The direct workers' schedule, data-wise as well as category-wise, indicates the worker strength required for accomplishing the scheduled work. The past performance data is invaluable for conceptualising manpower forecasts. For example, the actual workers planned for a building project are shown in **Appendix G**. It can roughly indicate the effort in man-months and the peak manpower required for similar building projects. But, then, no two projects are similar in nature, and the manpower schedule for each project has to be compiled separately.

The activity bar chart of construction work schedule with its commencement and completion dates of each activity for work-item, forms the basis for developing direct schedule of workers. Since, each activity has a specified duration, work content, and manpower required, for its accomplishment, the daily average manpower required for each scheduled activity can be assessed as:

Quantity of work × labour productivity standard in man-days ÷ duration in days

The ratio of skilled and unskilled workers in a construction team depends upon their characteristics and the nature of work. A typical skilled and helper ratio, used for building construction by a company in the Middle East, employing workers, is shown in Appendix G. The date-wise aggregation of manpower required for the scheduled activities (or work items), indicates the daily strength of manpower, category-wise, required to accomplish the scheduled work as per the project plan.

Daily manpower required for scheduled work
= Sum of manpower for on date construction of scheduled activity

The methodology of aggregating for forecasting manpower requirement is covered in **Chapter 6**. To cite an example, the number of workers required, category-wise and date-wise, for the 2000 Housing Units Project, worked out by aggregating the daily requirement of manpower for each scheduled activity, is shown in **Exhibit 7.3**.

7.4.2   Adding Indirect Construction Site Workers

Requirement of indirect workers, varies with the nature and size of the project. There are some yardsticks for assessing administrative persons, but on the whole the number of indirect workers that are required for each project has to be estimated and scheduled separately, on case-to-case basis. The indirect manpower requirement is related to the management functions. In construction projects, these functions can broadly be grouped as:

- Project office management;
- Design and drawing management;
- Estimation and contracts management;
- Planning and monitoring management;
- Project administration and personnel management;
- Cost and finance management;
- Materials management;
- Plant and equipment management;
- Quality management;
- Construction supervision management; and
- Support services management.

In general, the extent of indirect manpower, which is needed to perform the project functions depends upon the type and size of the project. A small project may need few indirect personnel to supervise and manage, whereas, a large-sized project may require more indirect manpower of various categories including managers, engineers, staff, skilled technical and administration assistants, and workers. Further, the period of employment of the indirect manpower varies with the need of the project.

Exhibit 7.3

2000 Housing Units Project Extract from Workers' Requirement Forecast

No.	Work description	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
1.	Construction Works												
	Carpentry Work												
	Furniture carpenter							20	39	50	50	50	
	Wood polisher								7	16	16	16	
	Shuttering carpenter	41	77	122	124	124	124	124	124	124	124	124	
	Carpenter helper	10	38	60	60	60	60	67	81	91	91	91	
	Masonry Work												
	Concrete mason	10	46	46	46	48	58	58	58	58	58	58	
	Blockwork and plaster mason	14	14	14	15	47	78	78	78	78	78	78	
	Tiling mason						121	34	50	50	54	54	
	Mason helper	30	40	40	40	40	40	92	108	108	112	112	
	RCC Steel Work												
	Rebar fabricator	22	45	74	91	99	104	104	104	104	104	104	
	Rebar helper	20	22	36	40	40	44	44	44	44	44	44	
	Painting Work												
	Painter	1	2	2	2	2	2	48	100	144	104	104	
	Painter helper		2	2	2	2	2	13	13	15	15	15	
	Electrical Work												
	Electrician	10	16	16	16	18	27	38	44	44	77	77	
	Electrical helper		1	5	5	15	24	34	39	39	82	82	
	Plumbing and Sanitary Works												
	Plumber/Pipe fitter	3	10	10	34	56	68	85	99	104	116	116	
	Plumber helper	1	10	10	34	50	59	59	87	93	109	109	

	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
Unskilled Work												
General helper	70	70	124	142	164	204	235	251	274	274	274	274
2. Mechanical Trades												
Light vehicle drivers	7	15	15	15	15	15	15	15	15	15	15	15
Heavy vehicle drivers	9	20	20	20	20	20	20	20	20	20	20	20
Equipment operators	1	18	38	55	57	59	59	59	59	59	59	59
Blacksmith	1	12	12	12	12	12	12	12	12	12	12	12
Welder	5	12	12	12	12	12	12	12	12	12	12	12
Sheet fabricator						18	24	24	24	24	24	24
Auto electrician	1	2	2	2	2	2	2	2	2	2	2	2
Mechanical diesel/petrol	6	8	10	10	10	10	10	10	10	10	10	10
Mechanic/operator helper	1	8	30	41	46	48	48	48	48	48	48	48
Riggers	27	36	36	36	36	36	36	36	36	32	32	32
Other categories	3	3	3	28	28	28	28	28	28	28	28	28
3. Administrative Staff												
Cook	4	10	10	10	10	10	10	10	10	10	10	10
Mess helper	1	26	26	26	26	26	26	26	26	26	26	26
Security staff	6	6	6	6	6	6	6	6	6	6	6	6
Administration helper	5	11	11	11	11	11	11	11	11	11	11	11
Total	**303**	**580**	**792**	**896**	**953**	**1118**	**1392**	**1566**	**1661**	**1702**	**1713**	
Months	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEB	MAR	APR
Working days in a month	25	24	25	25	24	25	24	24	22	20	23	24
Working days cumulative	25	49	74	99	123	148	172	196	218	238	261	285

To cite an example, the indirect manpower for a small road construction project (contract value: $5 million; contract period: 12 months) employing special-purpose road-making plant and equipment is listed below:

Category	Employment Period (Week)
Project manager	72
Senior engineer	66
Supervisors (3)	54
Senior officer clerk	72
Junior office clerk	56
Draftsman	56
Stores officer	56
Stores assistant	40
Time keeper	56
Cost accountant	56
Field surveyor	56
Personnel carrier driver	56
Load carrier driver	56
Plant workshop foreman	56
Equipment mechanics	40
Others	56
General helpers	40

Note: Above figures exclude .covered under the direct workers.

The format given in **Table 7.4** can be used to assess the indirect manpower of a project. The period of employment for each category can then be determined and its forecast plotted graphically on the project calendar.

7.4.3 Adjustments for Daily Manpower Requirement

The daily forecast of manpower can best be considered as an approximate estimate of the work force that is required under the normal operating conditions. The factors, such as learning process, weather conditions, labour turnover, strikes, absenteeism, sickness and the overtime working policy affect day-to-day aggregated manpower requirement. Though, it is difficult to quantify such variables, for planning, it proposes the aggregated manpower in each category, which may be increased by 5% or so catering these factors.

On the other hand, it is also possible to decrease manpower. Though, it is difficult to replace skilled workers by machines, the overall strength of the work force can be reduced by increasing production as follows:

Table 7.4

Project Management and Administration Group Indirect Manpower Data Sheet

S. No.	Departments	Manager		Senior Engineer		Junior Engineer		Supervisor		Staff			Workers		
		No	Period	No	Period	No	Period	No	Period	Category	No	Period	Category	No	Period
1.	Office management														
2.	Planning management														
3.	Technical management														
4.	Contract management														
5.	Personnel management														
6.	Materials management														
7.	Equipment management														
8.	Cost management														
9.	Finance management														
10.	Quality management														
11	Safety Management														
12.	Construction Management														

- Replacing unskilled labour by machines, wherever feasible, in jobs like loading, unloading, shifting, bar-cutting, etc.;
- Using appropriate and efficient tools as equipment;
- Constantly improving the methods of production;
- Increasing production through improved working conditions and incentives;
- Implementing the job-oriented financial incentive schemes; and
- Training workers to overcome the initial learning period.

In particular, overtime work, based on job-oriented financial incentive schemes, if properly implemented, can cut down the daily manpower requirement by a substantial amount, say 10–15%, and save the overheads relating to direct manpower.

❑ 7.5   ORGANISING PROJECT MANPOWER INTO RESPONSIBILITY CENTRES

7.5.1   Nature of Groups

The project manpower organisation depicts the hierarchy of organisational groups of people. Each group is headed by a leader. Each leader is assigned specific tasks, resources, responsibilities, and authority, that enables him to manage the group, efficiently and effectively for accomplishing the assigned objectives.

The number of organisational groups depend upon the magnitude and complexity of a project. A simple project may have only a few groups, while, a large complex on the other hand, may have more groups.

In a major project, each organisational group is usually headed by a manager. To illustrate, the outline organisational structure of a typical Housing Project as shown in **Exhibit 7.1**. The project manpower groups can be broadly divided into the following function units:

a. *Command and control group:* To manage the project and provide necessary logistic support.
b. *Construction task forces:* To execute the construction work.
c. *Resource/Support centres:* To provide men, materials, and machinery support to the construction task forces.

7.5.2   Command and Control Group

This group includes the project manager and his key staff. The Command and Control key staff of a medium-sized project would include the following:

- Planning and monitoring staff;
- Costing and contract administration staff;
- Technical staff, including the manpower of design and drawing office, site laboratory and technical library;

- Administration and personnel staff and workers connected with temporary housing, catering, camp utility services, medicine and welfare, safety and security, and other facilities, for the entire project;
- Materials handling staff and workers;
- Plant and machinery workshop engineers, staff, operators, mechanics, drivers, electricians, fabricators, welders, riggers, and so on; and
- Finance management and cost accounting staff.

Command and control staff falls in the category of indirect manpower.

7.5.3   Construction Task Forces

These are responsible for transforming inputs into outputs. The construction task forces of the typical Housing Project, as is evident from its organisational chart, include the following:

a. Building structure construction task force.
b. Precast building production and erection task force.
c. Building finishes construction task force.
d   External services construction task force.

A construction task force consists of many work centres, where a work centre is entrusted with the execution of a group of activities constituting one or more work packages.

A task force generally operates without much interference from the other executing agencies. It is an independent and significant unit of project organisation. It is fully supported with design and drawing packages, construction plan and allocated resources. It has a specified work scope and assigned performance objectives **Figure 7.1**.

In a project, direct manpower is divided into several construction teams, with each having a clearly defined task assigned to it. These teams possess the skill to perform their respective tasks. They are formal groups with informal bondage, where each person understands the significance of other. The strength of a construction team depends upon the nature of the task, which may range from 2 to 30 manpower.

Each team consists of a pre-determined category of tradesmen, skilled and unskilled. It is headed by a team leader, who may be an engineer, a fore-man, a change-hand, a labour sub-contractor, or even an experienced skilled worker. Some example of these teams, also called as crew or gangs, are brick-layers team, steel fixers team, concreter team, plasters team, tileseters team, painters team, plumbers team, electricians team, and so on.

The construction teams are combined together to form various work groups. Each work group is entrusted with the task of executing one or more work-packages. Depending upon the volume of work, each work group consists of one or more construction teams. Each team is headed by a supervisor, who may be a charge-hand, fore-man or a labour sub-contractor.

Figure 7.1

Construction Task Force Hierarchy and Relationship

Level of Command	Pyramid of Hierarchy	Responsibility
Taskforce commander	Manager	Production Responsibility Centre
Group commanders	Supervisor	Work Centre or Production Groups
Team leaders	Operative charge-hand	Work teams

Construction Task Force

Production Groups PG 1   PG 2   PG 3   PG 4

Work Teams Team 1   Team 2   Team 3   Team 4   Team 5

Pattern of Relationship
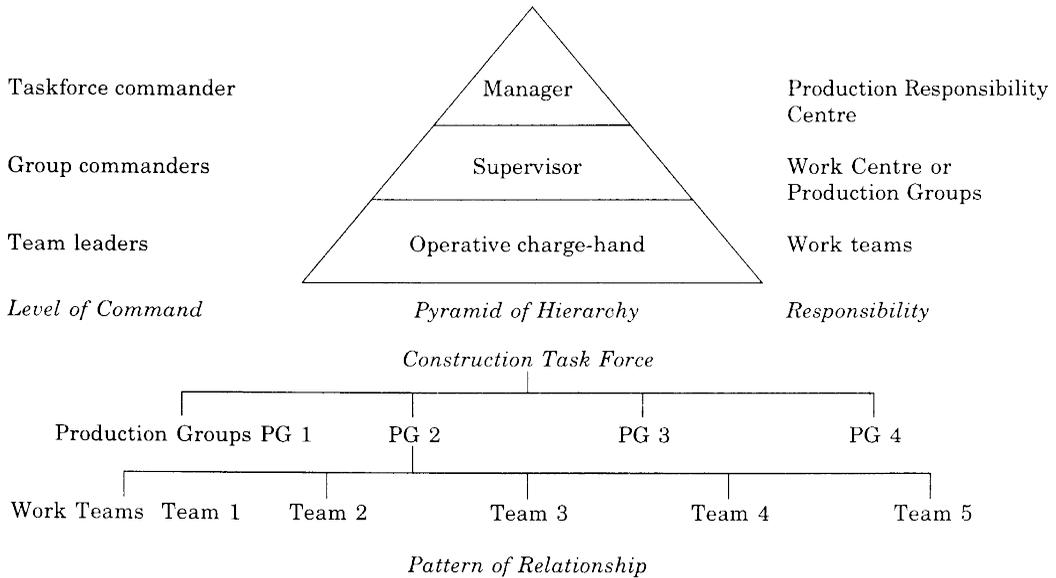
7.5.4   Support and Servive Responsiblitiy Centres

These centres provide construction centres with technical support, materials, manpower, equipment, and general services, like accommodation and temporary utility services. Some of these centres contain capital-intensive machinery and are self-supporting divisions. Examples of such investment-oriented centres are: ready-mix concrete production plant, steel reinforcement fabrication workshop, GRC elements manufacturing factory, metallic doors and windows fabrication unit, plant and machinery operation, and maintenance establishment. Support centres manpower is a mix of direct and indirect manpower.

APPENDIX G

Construction Workers Financial Incentive Scheme

❑ G.1   INTRODUCTION AND SCOPE

The project management aims at achieving objectives in an economical manner. It employs motivational tools in order to increase production and productivity. The art of motivating lies in creating environment, developing systems, and directing efforts in such a way that they meet the organisational goals as well as the needs of those, who are participating in the process, with everyone working enthusiastically, as one team under the leadership of the project manager.

❑ G.2   INCENTIVE SCHEME OBJECTIVE

Incentive is defined as 'the stimulation of effort and effectiveness by offering monetary inducement or enhanced facilities.' An incentive may be monetary or non-monetary depending on the requirement. It may be given either to an individual worker or a group of workers. The purpose of a financial incentive plan is to induce the worker to increase productivity and, by producing more, to secure a higher wage, while, at the same time affecting savings in production cost per unit.

The monetary inducement motivational approach, in general, can be divided into approach and financial incentive schemes. In a construction project, the motivational approach is to create a healthy work environment. The financial incentive scheme benefits the participants in the following ways It assists the project management in increasing production and productivity, without any appreciable increase in estimated costs, by curtailing supervision time, obtaining reliable feedback in progress of work and productivity, and exercising effective control on the employment of workers. The feedback also generates output information for planning and costing future works and improving incentive scheme. It helps workers, in increasing their earnings and gaining job satisfaction, without affecting the estimated work costs . It also encourages workers to develop better productive methods of working.

❑ G.3   TYPES OF INCENTIVE SCHEMES

In the construction industry, many financial incentives schemes have been developed with the intention to motivate workers. These financial incentives may vary with the type of project, nature of task, and employment teams of workers. Broadly, the financial incentive schemes can be divided in the following categories:

1. Time-related schemes: Employee is paid according to the overtime worked in proportion to the basic hourly wages and regulatory measures.
2. Job-related schemes: Employee is paid according to the measurable completed job.
3. Lump-sum work payment: Employee is paid according to:

   - Time saved from standard time fixed for completing the job, and/or
   - A lump-sum amount paid for completing the fixed quantity of a specified job.

4. Saving sharing bonus: These can be paid as bonus after a pre-determined time, say, quarterly, half- yearly or yearly.

❑ G.4 PRODUCTIVITY FEATURES OF FINANCIAL INCENTIVE SCHEME

The basis of financial incentive schemes is the setting of attainable output target rates for time or task. Generally for workers team, these output targets are derived from the productivity standards.

To quote example, the output target set for work item of building construction works in a project in UAE contained payments based on job related work done scheme , these are given in **Table G.1** and **Table G.2**.

Similarly output norms for MEP activities can be developed as shown in **Table G.2**.

❑ G.5 GUIDELINES FOR DESIGNING FINANCIAL INCENTIVE SCHEME

The following guidelines can help in designing a financial incentive scheme for the construction workers. The scheme should be:

- Attainable enough, so that the workers may find prospects of higher earning than their guaranteed minimum wages.
- Simple enough, so that the workers can easily comprehend it.
- Specific enough, so that the output can be measured without any controversy.
- Concise enough, so that the unforeseen and unavoidable holdups in progressing works can be easily determined and workers compensated for the time wasted during execution.
- Supervised enough, so that work progresses smoothly as per standard engineering practices and quality specifications.
- Comprehensive enough, so that all the statutory requirements are fulfilled.

Finalising, a financial incentive scheme, for a given work is a difficult process. An incentive scheme needs to be designed carefully. It is difficult to sell to workers. It faces teething problems during its implementation. Once implemented, it cannot be altered without concurrence of the affected workers. With all its drawbacks; however, an incentive scheme is still necessary to induce the workers to give their best. In conclusion, it can be said that workers work harder, if there is a financial reward linked to their performance, and the management saves upon time and costs if it is properly implemented.

Table G.1

Typical Building Construction Project Workers' Production Planning Data for Building Works

S. No.	Activities	Gang Size				Output per day (8 hours)
		Units	Skilled	Un-skilled		
1.	Excavation in ordinary soil (manually)	CM	—	2	7.00	
2.	Backfilling with excavate earth (manually)	CM	—	3	15.00	
3.	Concrete mixing and pouring in place	CM	2	10	17.50	
4.	Making, fixing and removing of fairface formwork	SM	2	1	10.00	
5.	Making, fixing and removing of ordinary formwork	SM	2	1	11.50	
6.	Reinforcement making & fixing	MT	2	1	0.30	
7.	B.R.C. fabric cutting & fixing	SM	2	1	165.00	
8.	Bitumen paints (2 coats)	SM	—	2	40.00	
9.	Blockwork an plaster (including scaffolding upto 4)					
	(i)	Solid blockwork	SM	2	2	15.00
	(ii)	Hollow blockwork	SM	2	2	17.00
	(iii)	Fairface blockwork	SM	2	2	12.00
	(iv)	Internal plaster (single coat)	SM	2	2	30.00
	(v)	Internal plaster (double coat)	SM	2	2	20.00
	(vi)	External plaster (single coat)	SM	2	2	20.00
	(vii)	External plaster	SM	2	2	15.00
	(viii)	Screed in flooring (upto 75 mm thick)	SM	2	2	20.00

(ix)	Erection of scaffolding (above 4 m upto 15 m nt)	SM	—	2	35.00
(x)	Dismantling of scaffolding)	SM	—	2	100.00
10.	Tiling work				
A	Ceramic wall tiles	SM	1	1	6.00
B	Ceramic floor tiles with cement back	SM	1	1	7.50
C	Ceramic tiles with adhesive backing	SM	1	1	7.50
D	Mosaic tile work	SM	1	1	9.00
E	Mosaic skirting	RM	1	1	27.00
F	P.V.C. tiles work with adhesive	SM	1	1	45.00
G	P.V.C. skirting with adhesive	SM	1	1	60.00
H	P.V.C. steps	No.	1	1	5.00
I	Mosaic steps making	No.	1	1	5.00
J	Mosaic sterps fixing	No.	1	1	6.00
11.	Site flooring	SM	1	1	2.50
	Situ skirting	RM	1	1	8.75
	Situ steps	RM	1	1	1.50
12.	Threshold fixing	No.	1	1	12.00
13.	Sanitary accessory fixing (including cutting of fixed tile if necessary)	No.	1	1	10.00
14.	Marble work-Floor	M2	1	—	10.00
15.	Painting				
(i)	2 Coats of Snowcem Type	M2	1	—	24.00
(ii)	3 Coats of emulsion	M2	1	—	12.00
(iii)	4 Coats of enamel paint	M2	1	—	10.00

Table G.2

Typical Building Construction Planning Data for Mechanical and Electrical Works

Activity	Unit	Skilled	Semi-Skilled	Unit/day (8 hours)	Remarks
Mechanical					
Duct Installation	LM	2 DM	2 ADM	8	DM – Ductman ADM – Asst. DM
Duct Insulation	LM	1	1ADI	8	DI – Duct Insulator ADI – Asst. DI
Dampers/VCD Installation	NO.	1 DM	1ADM	5	
Diffuser and Grill Installation	NO.	1 DM	1ADM	15	
Chilled Pipe Installation	LM	2PF	2PH	20	PF – Pipe Fitter PH – Piping Helper
Chilled Pipe Insulation	LM	2PI	2API	20	PI – Pipe Insulator API – Asst. PI
FCU Installation	NO.	1-PF	2-PH	4	
FCU Connection and Termination	NO.	1-PF	1-PH	4	
Door Curtain Installation	NO.	1-PF	1-PH	4	
HRU Installation and Connection	NO.	1-PF, 1-DM	2-PH, 2-ADM	0.1	10 day/unit
AHU Installation and Connection	NO.	1-PF, 1-DM	2-PH, 2-ADM	0.1	10 day/unit
FAN Installation and Connection	NO.	2-DM	4-ADM	1	
CHW Pump Installation and Connection	NO.	1-PF, 1-DM,	2-PH, 2-ADM	0.33	3 day/unit
Plumbing					
Install Pipes and Supports	LM			12	
Install Energy Pipes	LM	1-PF	1-PH	13	
Install U/G Drainage Pipes	LM	1-PF	1-PH	10	
Install Floor Gully	NO.	1-PF	1-PH	3	
Manhole GRP Lining	NO.	1-PF	1-PH	3	
Manhole Covers	NO.	1-PF	1-PH	3	

Install Sanitary Wares	NO.	1-PF	1-PH	2	
Install Plumbing Final Fix	NO.	1-PF	1-PH	3	
Install Water Tanks (Cap. 1000 litres)	NO.	1-PF	2-PH	0.5	2day/Unit
Water Tanks Connection (Cap.1000 litres)	NO.	1-PF	1-PH	1	
Install Water Pumps	NO.	1-PF	2-PH	0.5	2 day/Pump
Water Pumps Connection	NO.	1-PF	2-PH	1	
Fire Protection					
Install Pipes and Supports	LM	1-PF	1-PH	12	
Install Sprinklers	NO.	1-PF	1-PH	8	
Install Fire Supression Sy	NO.	1-PF	1-PH	8	
Electrical					
Install Lightning Conductor Tape and Clamp	NO.	1-EL	1-EH	2	EL – Electrician
EH – Electrical Helper					
Install Earth Conductor and Pit	NO.	1-EL	1-EH	2	
Install Cable Tray/ Ladder	LM	1-EL	1-EH	15	
Install Cable Trunking/ Conduit	LM	1-EL	1-EH	20	
Install G.I Conduit	LM	1-EL	1-EH	25	
Pulling LV Cable	LM	3-EL	3-EH	50	
Pulling Wiring	LM	1-EL	1-EH	250	
Install Light Fittings	NO.	1-EL	1-EH	10	
Install Switches and Socket	NO.	1-EL	1-EH	12	
Install and Connect DB	NO.	1-EL	1-EH	0.5	2 day/Unit
Install and Connect Panel	NO.	1-EL	2-EH	0.17	6 day/Unit
Install and Connect LV Panel	NO.	1-EL	1-EH	0.1	10 day/Unit

Planning Construction Materials

Broadly, the term 'materials' denote all the purchased items that are utilised at the project site, including construction materials, supporting plant and equipment spares, and administrative facilities requirements and stores. Supporting plant and equipment spares consist of all machinery, vehicles, custom-build form work, construction equipment, and their operational repair and maintenance materials. Construction materials, on the other hand cover all types of materials that is been used in construction, including bulk raw materials, finishing materials, electrical and mechanical fittings, fixtures, devices and instruments, which are incorporated during the construction of permanent works and temporary supporting works at site.

Planning of construction materials involve; identifying materials, estimating quantities, defining specifications, forecasting requirements, locating procurement sources, getting samples of materials approved, designing materials inventory, developing procurement plans, and monitoring flow of materials, till the connected construction is completed. In construction projects, materials account for more than 40% of the project cost. A small saving in materials cost, say even 5%, through efficient management of materials, can result in a large contribution specially, when competitive bidding is for small profit margins.

Efficient materials management, in project environments call for an integrated approach covering numerous functions, such as materials planning, purchasing, inventory control, store-keeping and warehousing, handling and transportation, codification and standardisation, and the disposal of surpluses. Materials planning, which is the key function of materials management, is closely linked with project planning and control set-up. Both of these works together develop a procurement plan and stocking of construction materials, so as to provide at the site materials, right quality in right quantity at the right prices from the right sources at the right time.

In contracted construction projects, materials management is the responsibility of the contractor, who is executing the work. Accordingly, in this chapter, a construction material planning is viewed from the contractor's angle. Construction materials planning in building construction projects involve a variety of materials. The planning process described in the chapter is illustrated with examples from such projects. The costing and monitoring of construction materials, is covered in **Chapters 11** and **14**, respectively. This chapter is divided into the following sections:

1. ABC Classification of Construction Materials
2. Materials Wastage Standard
3. Materials Provisioning Process
4. Materials Inventory Basics
5. Inventory Planning Processes
6. Application of Value Engineering in the Procurement of Materials
7. Use of oprations Research in Materials planning

Linear programming technique applications for solving resources allocation, minimising transportation costs, and maximising contribution are given in **Appendix H**. The Supply Chain Management, which falls under materials procurement management, is not covered in this chapter.

❑ 8.1 ABC CLASSIFICATION OF CONSTRUCTION MATERIALS

8.1. 1 Concept

In the manufacturing industry, where manufactured end-products are usually similar, the materials used are broadly divided into: *repetitive* and *non-repetitive* items. The repetitive items include raw materials that other stores consumed regularly for production, maintenance, and administration. All other items, such as capital purchases of plant and machinery, including, its major repairs, capital goods, and special one-time requirements for various jobs, are categorised as non-repetitive items. In the manufacturing industry, repetitive items are included in the regular stock list and their procurement and inventory is generally, guided by the ABC analysis technique explained in subsequent paragraphs. On the other hand, non-repetitive items are inducted when required. Each item is considered for purchase on its own merit and it is subject to selective inventory control.

However, in construction, the type and quality of construction materials differ from project to project. Although some basic materials, like cement, steel, water, and timber are common items, others vary with the type of the project. For example, most of the finishing materials that is been used in housing projects may not be required in industrial projects.

The primary purpose of classifying materials is to control quality, cost, and timely supply. There are many factors that need consideration while classifying materials, which include storage space, shelf life, supply reliability, inventory costs, ease of identification, construction sequence, transportation requirement, price, procurement time, procurement source and project life. In general, the construction materials can be grouped into anyone or a combination of the following categories:

- Bulky, one-time purchases, repetitive use, and minor materials.
- Vital, essential and desirable materials;
- Indigenous and imported materials;
- High price, medium price and low-price materials; and
- High usage value, medium usage value and low-usage value materials.

The most commonly used method for classifying construction materials is to group them into high-value, medium-value, and low-value materials. This classification is achieved using the ABC analysis approach (**Figure 8.1**).

Figure 8.1

Graphical Representation of ABC Analysis Concept
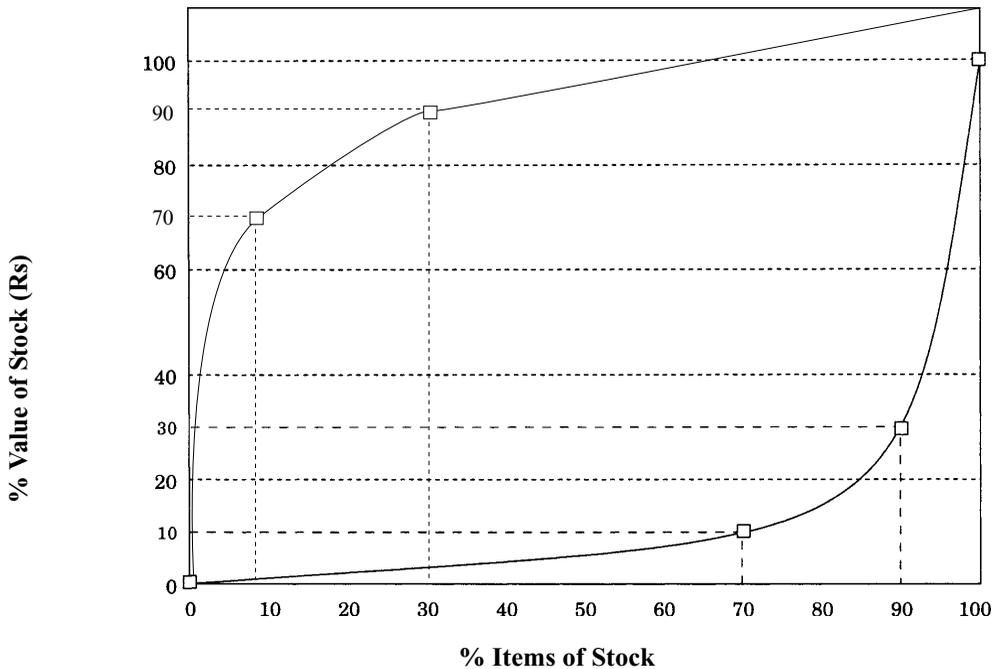
Note:
- 10 % Items cost 70% of Stock Usage Value
- 20 % Items have 20% of Stock Usage Value
- 70 % Items account for 10% of Stock Usage Value

The materials management technique of ABC analysis is generally used for inventory control of regular stock items. Studies show that regular stock items, depending upon their periodic requirement and costs (say yearly), can be grouped into three groups of materials, i.e. A, B and C, generally confirming to the following pattern:

Group class	Total items	Inventory costs
A	10%	70%
B	20%	20%
C	70%	10%

a. *Group A Items: These* are high usage value items, which account for 70% of the inventory cost. Number of such items is about 5%–15% of all items.
b. *Group B Items: These* are medium usage value items, which account for nearly 20% of the inventory costs. Their number is also in the range of 15%–25% of the total number of items.

c. *Group C Items: These* are the remaining about 65%–75% of the items, which account for hardly 10% of the inventory cost.

The above concept of ABC analysis can be applied for the categorisation of repetitive construction materials, where the period of usage can be taken as the project completion period or on a yearly basis. The number of items can be considered as those required for the project execution. For further simplification, these can be restricted to the construction materials estimated for the works.

The prerequisite for applying the ABC analysis technique, is that the project should have a standardised bill of materials, which lists the physical quantities (including standard wastage), unit rate, and total cost for each item. The following is the format of a bill-of-materials table.

Form: Bill of Materials Consumption in Project Life

S. No.	Item of Materials	Unit	Quantity	Rate	Amount
1.					
2.					

8.1.2   Methodology

In performing ABC analysis, the focus is to identify the regular stock items with their annual or project usage value and then, classify and rank these items using the ABC analysis technique (or similar 80/20 Parato's principle). An example from Residential Building of 2000 Housing Project is depicted in **Exhibit 8.1**.

The ABC group of construction materials can thus be grouped in the following manner:

- Identify materials required and esti mate quantity and quality of each material.
- Obtain the approximate unit rate for each item;
- Assess the requirement during the period under consideration, i.e. yearly or project completion basis;
- Determine the usage value of each type by multiplying the quantity required with the corresponding unit rates;
- Calculate the percentage usage value of each material with respect to total project or yearly usage cost. Write this percentage against each item in the appropriate column;
- Arrange the items in the descending order of usage value;
- Consider materials in the descending order of usage value. Compute cumulative usage value against each item;
- Draw two horizontal lines demarcating the descending order of the cumulative purchase values at 70% level and 20% level; and
- The three groups separated by the above two horizontal lines starting in descending order of usage value can then be classified as 'A', 'B' and 'C' groups.

Exhibit 8.1

Residential Building Sub-project: ABC Classification of Direct Material

	S. No.	Item and Description	Amount (in 000 $)	% to Total Amount	Rank	Class
I	**Bulk Materials**					
	1.	Cement	6235.88	19.43	1	A
	2.	Sand	2052.63	6.39	3	A
	3.	Aggregate	1844.21	5.75	5	A
	4.	Admixtures	1540.62	4.80	6	A
	5.	Steel	4884.37	15.22	2	A
	6.	Weld mesh	153.91	0.48	27	B
	7.	Binding wire	84.17	0.26		C
	8.	Bitumen	36.40	0.12		C
	9.	Anti-termite chemicals	160.32	0.50	26	B
	10.	Polythene sheets	114.77	0.36		C
	11.	Imported soil	294.99	0.93	19	B
	12.	Inserts for precast	1375.34	4.28	7	A
	13.	Hardwood	39.57	0.13		C
	14.	Softwood	135.70	0.42		C
	15.	Teakwood	2.18	0.02		C
	16.	Commercial plywood	12.85	0.05		C
	17.	Teakface plywood	5.63	0.02		C
II	**Wiring**					
	18.	PVC Conduits and accessories	105.21	0.33		C
	19.	Switches	54.46	0.17		C
	20.	Socket outlets	102.39	0.32		C
	21.	6 mm^2 electric cable	5.10	0.02		C
	22.	Electric buzzer	28.11	0.09		C
	23.	Telephone cable	2.21	0.01		C
	24.	Shaver unit	28.11	0.09		C
	25.	Rawl plugs	59.60	0.19		C
	26.	Screws	59.60	0.19		C
	27.	Telephone socket	1.97	0.01		C
	28.	Armored cable	125.40	0.39		C
	29.	2.5 mm flexible wire	89.25	0.28		C
	30.	4 mm^2 flexible wire	36.63	0.12		C

III	**Screed**					
		Cement	Included in S. No. 1			
		Sand	Included in S. No. 2			
IV	**GRC Panels**					
	31.	GRC Panels	2006.76	6.25	4	A
V	**PVC Plumbing**					
	32.	PVC Pipes and accessories	843.40	2.64	10	A
VI	**GI Plumbing**					
	33.	GI pipes and fittings	179.68	0.56	24	B
	34.	40 mm valves	18.47	0.07		C
	35.	25 mm valves	56.91	0.18		C
	36.	20 mm valves	28.57	0.09		C
	37.	15 mm valves	85.66	0.26		C
	38.	Hot water pipe	92.34	0.29		C
	39.	Teflon tape	10.00	0.04		C
	40.	Dense tape	18.70	0.07		C
VII	**A/C Ducting**					
	41.	GI Sheet 24 g	136.93	0.43	30	B
	42.	GI Sheet 22 g	126.43	0.39		C
	43.	GI Sheet 18 g	17.21	0.05		C
	44.	I-Glasswool	17.73	0.05		C
VIII	**Staircase Metal Works**					
	45.	M.S. flat/round	14.04	0.05		C
	46.	40 mm GI pipe	98.48	0.32		C
	47.	Inserts/bolts	19.00	0.06		C
	48.	Sealant	1.32	0.02		C
IX	**False Ceiling**					
		Softwood	Included in S. No. 14			
	49.	Metal screws	14.04	0.04		C
	50.	Wood screws	1.41	0.02		C
	51.	Plastic rawl plugs	2.04	0.02		C
	52.	Asbestos sheet	112.68	0.36		C
X	**Ceramic/Glazed Tiles**					
	53.	Tiles Type A	167.33	0.52	25	B
	54.	Tiles Type B	134.93	0.42		C
	55.	Tiles Type C	200.80	0.63	23	B
	56.	Tiles Type D	802.25	2.50	11	B

57.	Tiles adhesive	67.27	0.22		C
58.	Bonding agent	14.34	0.05		C
59.	Tile grout	29.14	0.09		C
XI	**Doors/Windows including**				
	Shuttering/Glazing				
	Hardwood	Included in S. No. 13			
	Softwood	Included in S. No. 14			
	Commercial plywood	Included in S. No. 16			
	Teak faced plywood	Included in S. No. 17			
60.	Hot pressing glue	1.71	0.02		C
61.	Nails/pins		0.02		C
62.	Wood screws		0.02		C
63.	Door/windows profiles		1.99	13	B
XII	**Sanitary Fittings**				
64.	Wash hand basin	64.87	0.16		C
65.	Shower tray	29.95	0.09		C
66.	European water closet	68.64	0.22		C
67.	Bidet	63.68	0.20		C
XIII	**Painting**				
68.	Spray plaster	421.33	1.31	15	B
69.	Plaster spatula	1.00	0.02		C
70.	Plastic emulsion paint	228.95	0.71	22	B
71.	Oil paint	44.30	0.15		C
72.	Paint primer	147.29	0.46	28	B
73.	Paint putty	350.70	1.09	18	B
74.	Fiber glass scrims	6.01	0.03		C
75.	Masking tape	1.20	0.02		C
XIV	**Electrical Fittings**				
76.	Electrical holders and fittings	501.00	1.56	14	B
XV	**Kitchen Cabinets/Wardrobe**				
77.	Kitchen cabinet	938.69	2.92	9	A
78.	Wardrobe	1030.88	3.21	8	A
79.	Kitchen sink	70.66	0.23		C
XVI	**PVC Tiles**				
80.	PVC tiles	411.41	1.28	16	B
81.	PVC skirting	372.63	1.16	17	B
82.	MV cement glue	40.03	0.13		C

	83.	SV cement	10.30	0.03		B
	84.	Bar emulsion	256.00	0.80	20	B
	85.	Levelling compound	1.90	0.02		C
	86.	Polishing stone	22.50	0.07		C
XVII	**PVC Handrail**					
	87.	PVC handrail	7.70	0.02		C
XVIII	**Roof Treatment**					
	88.	Roofing felt	801.93	2.50	12	B
	89.	Bitumen primer	146.97	0.46	29	B
	90.	Super penetration primer	78.25	0.24		C
		Polythene sheets	Included in S. No. 10			
XIX	**External Finishes and**					
	Miscellaneous Items					
	91.	Waterproofing compound	230.46	0.72	21	B
	92.	Terrazo tiles	19.95	0.06		C

Exhibit 8.1 shows the tabulated A, B and C grouping of construction materials with respective usage values of a typical residential buildings construction project. It may be noted that:

a. A, B and C grouping is based on the estimated consumption costs of materials over a selected period. A and B refer to items that are ranked and the remaining are 'C' items.
b. The classification based on 70%, 20% and 10% of the purchase costs is not rigid. This percentage can be varied to suit project procurement sources.
c. 'A' items need strict control; while, 'B' items need fairly tight control. For 'C' items, control can be of moderate type.
d. The number of Economical Order Quantities (EOQ) for 'A' and 'B' items can be worked out by using the EOQ technique (described under materials inventory).

8.1.3 Applications

In materials management, the ABC analysis is used in areas that needs selective control, such as policy development, procurement planning, inventory planning and control, quality inspection, and store-keeping. For example, ABC analysis can assist in developing policy guidelines for exercising selective control on material supplies as shown in **Table 8.1**.

It is worth noting that the ABC analysis depends upon the usage value of the consumed material item during the project life and not on the unit cost of the material. It does not rely on the importance of the material and is not related to construction sequence. A, B and C, items can be further split up into categories like locally available items and imported items. Further, locally available materials, which are in large size and quantity, can be taken out of the category of A, B and C items, and can be classified as a separate item.

Table 8.1

Use of ABC Analysis for Developing Policy Guidelines

Policy Consideration	'A' items	'B' items	'C' items
Degree of control required	Strict	Moderate	Loose
Forecast accuracy	Accurate quantities	Approximate quantities	Rough quantities
Authority for ordering purchases	Senior level	Middle level	Junior level
Suppliers to be contacted for enquiries	Maximum suppliers	3 to 5 reliable suppliers	2 to 3 reliable suppliers
Safety stock	Low	Moderate	Adequate
Ordering frequency	When required	EOQ basis	Bulk ordering
Follow-up need	Maximum	Moderate	When necessary
Monitoring inflow and stock status	Weekly	Monthly	Quarterly
Control reports	Weekly	Monthly stock-taking	Quarterly accounting period

❑ 8.2 MATERIALS WASTAGE STANDARD

There is inherent wastage of materials during their usage associated with all types of materials. For example, the actual requirement of concrete for the floor slab of a building may be 2% more than the theoretical quantities measured from the drawing, as certain wastage does occur while placing concrete, specially, due to inaccuracies in levelling of form work. Further, the quantities of aggregate, sand, cement, and water though correctly weighed prior to mixing, also have a certain element of handling wastage. Similarly, some steel gets wasted when the standard bars are bent into designed lengths and shapes for reinforcement work. Some wastage is inevitable in actual work, which is generally expressed as a percentage of the materials, calculated theoretically from the quantities of work involved, and is termed as 'Standard Wastage'. The total quantity of materials to be provisioned should cater for the standard wastage by increasing the theoretical quantity, proportionately as given below:

$$\text{Materials to be provisioned} = \text{Theoretical quantity of material} \times \left\{\frac{100 + \text{standard wastage (\%)}}{100}\right\}$$

Standard wastage of the construction materials depends upon many variables, such as the nature of work, type of materials, and method of application. The standard wastage can best be specified from experience. The typical standard wastage that can be considered while estimating some of the materials in a housing project are shown in **Table 8.2**.

It may be noted that standard wastage caters for wastage during utilisation only for causes, which are considered beyond control at the site. In addition, to the uncontrollable wastage, there is

Table 8.2

Construction Materials Wastage Planning Norms

S. No.	Type of Materials	Planned Wastage
1.	Cement	2%
2.	Sand	10%
3.	Aggregate	5%
4.	Concrete structural	2%
5.	Concrete blinding (lean)	10%
6.	Reinforcement steel bars	3%
7.	Reinforcement steel mesh	10%
8.	PVC sheeting	15%
9.	Steel for windows	7%
10.	Timbering in trenches	5%
11.	Stone masonry	5%
12.	Marble lining	20%
13.	Wood for door frames	5–7.5%
14	Wood for shutters	10%
15.	Wood for flooring/walling	5–10%
16.	Sheet roofing	2.1/2%
17.	Tile roofing	5%
18.	Floor tiling	2–5%
19.	Wall tiling	3%
20.	Pigments (for colours other than natural grey)	5%
21.	Paints	5%

wastage/pilferage, which fall in the category of controllable wastage. The main causes of controllable wastage at various stages can be due to the following:

- Wastage on account of designers specifying non-standard materials having unattainable specifications;
- Wastage due to incorrect purchasing resulting in over buying, wrong buying, unnecessary buying and untimely buying;
- Wastage in transportation and handling including breakage and pilferage; and
- Wastage during storage resulting from deterioration, improper storage, breakage, obsolescence and theft.

Since, controllable wastage falls under the purview of the materials management staff, the additional provisions to compensate for such wastage should be made by them as to ensure that the right quantity and right quality of materials are available at the right time.

❏ 8.3 MATERIALS PROVISIONING PROCESS

Construction materials needed for a project work varies with the nature of the project. For example, in a road construction project, the type of materials required may be few in number, whereas, in the building construction project, it may run into hundreds. The determination of the type, quantity, and specifications of the construction materials needs a detailed study of the contract's documents, including the bill of quantities, drawings, specifications, pre-tender estimates, and preliminary vendor enquiries. Such a study consumes considerable time and is a systematic and gradual process. The materials provisioning process for each item generally considered in the order of requirement, follows the sequence outlined in **Table 8.3**. Broades materials procurement can be gronped under identification of materials package & purchase, material quality estimation and scheduling requirements, materils procurement in quires finalisation of sources of materials procurement and monitoring materials delivery schedule till materials of right quantity, right quality are received at site at the right Time.

Table 8.3

Materials Provisioning Process

1.   Study contract documents to identify items for purchase.
2.   Estimate quantities to be purchased.
3.   Float inquiry indents to locate sources of supply.
4.   Invite quotations from selected vendors.
5.   Analyse quotations received and vendors' pre-qualifications.
6.   Submit proposals for technical, financial and client's approval.
7.   Negotiate with vendors and finalise supply orders.
8.   Place purchase orders and monitor order execution.
9.   Conduit pre-shipment inspections, where necessary.
10. Inspect goods received at site and initiate action where warranted for in-transit losses/theft/damages, short shipments and rejections of sub-standard supply item.
11. Close materials supply contract after confirming no-further demand from concerned site manager. Inform accounts, planning, costing and the project manager, accordingly.

Materials breakdown specially, of bulk materials, can be determined from the bill of quantities, which contain work-items with quantities of work involved, generally, listed in the order of execution. Similarly, details regarding finishes can be read from the architectural drawings specially, the schedule of finishes. In case of, electrical and mechanical items, a detailed scrutiny is required to identify the item and its components. In some cases these scrutinize may have to be designed.

8.3.1 Identification of Materials Package

Materials package includes all types and qualities of materials that is needed to perform a given activity or a work-item. For example, the foundation concreting not only requires cement, sand, aggregate and water, but it may also need polythene sheets to be laid under the concreting surface. Further, each of these items should meet the contract specifications. Typical combinations of materials that need activity-wise for finishes in a building project are identified in **Exhibit 8.1**. This list also highlights that the materials should be identified activity-wise as non-availability of any one item can hold up the execution of activity.

8.3.2 Materials Quantity Estimation

Material quantities estimates are based on the abstract of quantities of work calculated by the quantity surveyors from the contract drawings. The work quantities when multiplied by the respective estimated materials required for a unit item of work, give the quantity of materials required for the activity. In particular, materials estimates must include wastage in materials, which occur during execution of work. **Table 8.2** shows typical wastage percentage, which may be included in the materials estimates of a building project.

The quantities of final materials, specially, of A and B items, which constitute the major portion of the materials costs, are then compared with the preliminary materials estimates that are prepared at the time of tendering to know the variations from the original estimates. In case of, appreciable variations, the approval of the appropriate authority is obtained prior to floating materials procurement inquiries/quotations.

8.3.3 Scheduling Materials Requirements

After the quantities of materials that are required for the work are evaluated; a usage schedule at the site based on the project construction plan is prepared with a view to evolve their delivery schedules and the stocking policy. The method of forecasting is covered in Chapter 6.

8.3.4 Materials Procurement Enquiries

Preliminary investigations for developing procurement sources of materials are made by floating enquiry indents. Materials enquiry indents consisting of quantities, specifications, and delivery times, are jointly prepared by the project planning cell and materials procurement department. These are then processed by the materials procurement department for inviting quotations with samples of materials, wherever applicable.

On receipt of the quotations, a comparative study of the price, quality, delivery time, terms of delivery, and payment terms is made jointly by, both, materials as well as project planning in charges. During the course of this study, vendors' proposals are compared with enquiry specifications and stipulated requirements leading to resulting deviations, which are examined for acceptability.

Thereafter, each acceptable quotation is analysed for prices, delivery timings, and payment terms.

Vendor's enlistment is based on its size, capability, past performance, market reputation, and, if necessary, these may be confirmed by a visit to the vendor's works. The key criteria for evaluating the potential of the supplier to deliver the right quantity product at the right time should include the following:

- Quality of the material and its past records, recent test reports, performance reports, performance reports from old users, etc.;
- Company's past performance and financial status; and
- Company's management team and their professional competency and engineering skills.
- Support services.

This study of various acceptable quotations is then compiled in form of a quotation comparison sheet for each of the major materials items. In particular, all deviations from stipulated specifications and delivery timings should be reviewed with the project manager and other concerned managers and if required, with the consultants also. Their views are ascertained, prior to preparing the quotation comparison sheet. These informal discussions in the early stages prior to the finalisation of the source for procurement can avoid costly delays at a later stage.

8.3.5   Finalisation of Source of Materials Procurement

The quotation comparison sheet can be best termed as a summary of the alternate proposals for the procurement of given materials. These proposals undergo further processing before making a decision about placing of purchase order. The various stages encountered, prior to the purchase decisions are as follows:

1. *Approval in principle for processing proposals*. The quotation comparison sheet containing various proposals has financial implications. In case, of major deviations from original estimates and budgeted funds, these can be discussed with the project manager prior to commencing further negotiations with the suppliers. This discussion strengthens the company's representatives engaged in further negotiations.

2. *Client's approval of proposed materials*. As per the terms of agreement and standard construction practices, the contractor submits proposals to the client/consultant for approval of materials. These proposals can be in the form of samples of materials, the manufacturer's write-up on the materials, the materials test results, its previous performance, or a combination of these. The proposals for approval of materials can be submitted to the client at any time prior to procurement. Generally, a contractor will like to get those materials approved, which are economical to him, whereas, the client's side will aim at approving materials, which in their opinion meet the quality requirement and give best performance. No procurement plan of materials can work unless the materials are approved by the client prior to the placing of supply orders for procurement. In major projects, contractors also get more than one vendor approved for the same type of materials as to ensure continuity of materials, in case of, breakdown of supplies from one vendor.

3. *Negotiations of terms of supply*. Final negotiations with the vendor prior to placing of order are carried out to evolve mutually agreed terms for supply particularly, with respect to the following:

- To finalise prices through negotiations by securing a better price offer;
- To finalise mode of transportation of materials up to site;
- To finalise the payment terms including the opening of the letter of credit, if required;
- To finalise prior delivery and post delivery inspection/quality control procedures with particular reference to the contract stipulations and design specifications;
- To finalise the materials delivery schedule; and
- To finalise guarantees and penalties.

Before closing the final negotiations, re-check is performed to ensure that the necessary documents, which are needed for manufacturing and making supplies, as per contract have been provided to the supplier vendor by the contractor.

8.3.6 Monitoring Materials Delivery Schedule

After the purchase order is placed with the vendor, a number of steps are necessary to ensure that the right quality and quantity of materials arrive at the site at the right time. These steps include the following:

a. Preparing and monitoring the materials sample approval, procurement plan, and data status as per date of movement schedule.
b. Conduct pre-transportation inspections, where necessary.
c. Obtain periodic information on shipment/transportation status.
d. Ready the necessary documents for clearing customs and other formalities during transit.
e. Plan in advance for receiving materials at the site. This includes unloading place; machinery for handling at site; persons for inspecting materials for correctness; storage arrangement and the construction site/persons that are to be intimated on arrival.
f. Assisting the construction management in checking the materials when received at the site for correctness of quality and quantity as per requirement and bringing out discrepancies, if any, to the notice of the materials management for further action, including timely replace-ment/reordering and claiming insurance/compensation if applicable.

Specimen of material procurement and monitoring sheet is given in **Table 8.4**

❑ 8.4 MATERIALS INVENTORY BASICS

8.4.1 Need for Inventory

The term 'inventory' implies the cost of materials in stock at a given time. Inventory could be of raw materials, construction finishes materials, tools and spares, etc. This stock of materials is

Table 8.4

Materials Procurement and Monitoring Sheet (Specimen)

Sl No.	Status		Item of Material	RE	#	Samples Plan			Procurement Plan										
	Samp	Proc		SM		Re-ciept	Sub-mission	Aproval	Prog. lead Date	Order confmn No	Order placed Date	No	Vendor Details	L/C Open-ing	Delivery Std essu-rence	ETA Bagh-dad	Site requirement Date	phases	Remarks
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
8.1.2			Solid Core Flush Door		S								Site Manufactured						
					A														
8.1.2			Semi-Solid Core Door		S								-do-						
					A														
					S														
					A														
					S														
					A														
8.2			Window		S														
					A														
8.2.1			Window sections		S				$22^3/_{82}$	R377							At earliest		
					A														

\# S. Scheduled
A: Actual

Sample: ☒ Order (Placed) — ☒ Placed
Procurement: ☐ Material — ☒ Received

held at project warehouse/sites to act as a cushion between supply and demand. The monetary value of inventory indicates the extent of investment that is required to maintain minimum stock of materials for the smooth running of the project. Higher inventory implies higher investment, whereas, less inventory carries the risk of supplies falling behind demand. A balanced inventory acts as a cushion between supply and site requirement till supplies are received. It includes predetermined safety stock to cater for slippages in delivery schedules. It is important to maintain an appropriate level of stock of materials so that there is neither shortage nor is there a waste in investment, by storing too much.

Generally, each project starts with zero material stock and after the left-outs are disposed off, it should end up with zero-stock. Ideally, each construction activity prior to commencement should have zero-stock; during execution there should be working stock sufficient for a very short period and should get replenished regularly as soon as it is about to finish; and finally, it should end up with zero-stock, when the activity is completed. But such an ideal materials stocking policy is rarely feasible in construction projects, as materials need for each activity have to cater for lead time, necessary to procure materials, build up sufficient working stock, hold safety stock, and at the same time, exercise economy in procuring materials. All these results in materials stock build-up at the project site.

Construction materials, stock costs money, locks up the capital invested for making purchases, and occupy built-in accommodation and open storage space. The magnitude of materials stock and inventory of each item depends upon many factors, which are discussed in subsequent paragraphs. The variety of items and their value pattern can be conceptualised using the ABC analysis, which indicates that around 10% of the materials stock items may account for 70% of the total value, while 70% of the items may amount to 10% of the total value of the stock.

It may be noted that the total number of construction materials items at any one time during peak stock period may run into hundreds and their corresponding value may be of the order of 5%–15% of the material cost. It is, therefore, necessary to hold a planned stock of construction materials at the project site to ensure a timely supply of the expected quantity of materials for smooth execution of planned construction activities with least investment on inventory.

Planning inventory means determining the timing and the size of the order. The demand of an item can be deterministic as well as probabilistic. The probabilistic models are used where the material requirements cannot be forecast, which is generally not the case in most of the construction projects. The EOQ inventory model covered in the following paragraphs relate to deterministic models. In deterministic inventory control, demand and the quantity of order called as Economic Order Quantity (EOQ) is assumed to be fixed, however, it can change depending upon changes in the planned progress of work.

8.4.2 Inventory Costs

Inventory costs terminology.   The following terms are used for evaluating inventory costs:

a. *Inventory Cost* is the cost of maintaining inventory. It comprises carrying cost and ordering cost.

b. ***Ordering Cost*** is the cost incurred in ordering materials for construction.
c. ***Inventory Carrying or Holding Cost*** is the cost that is incurred on storing an item till it is required
d. ***Demand*** is number of units required per period of time. This can be deterministic as well as probabilistic.
e. ***Lead-time*** is the time period elapsed between placing an order and its arrival in the inventory stock
f. ***Stock replenishment*** depends upon the source of materials procurement. If the stock is purchased from outside, than replacement is based on EOQ and if it is purchased locally specially bulky materials, such as sand and aggregate, then generally these are replenished on continuous requirement basis.

Cost components. Inventory cost (C) of an item of materials is made up of inventory carrying costs and ordering costs that is related as under:

$$\text{Inventory cost C} = \text{Ordering cost} + \text{Inventory carrying cost}$$

where,

$$\text{Ordering cost} = \text{Cost per Order} \times \text{Number of Orders} = Co \times N$$

and

$$\text{Inventory Carrying Cost} = \text{Carrying Cost of an Item} \times \text{Average Stock}$$
$$= Ci \times P \times (Q/2)$$
$$= (Ci \times P \times Q \times N)/2N$$
$$= (Ci \times A)/2N$$

Where,

C_i = Carrying cost expressed as % of unit price of an item.
P = Price per Item
Q = Quantity per Order
N = Number of Orders
A = Total Consumption Cost (Pre-determined)
  = Total Consumption Quantity × Unit Price
  = $Q \times N \times P$

Therefore,

$$\text{Inventory Cost (C)} = C_o \times N + \{(Ci \times A)/2N\}$$

8.4.3 Economic Order Quantity (EOQ)

Two important decisions that needs to be taken while planning repetitive materials inventory are; how much to order at one time and when to order this quantity. In other words, to decide the reorder quantity level and the reorder time cycle so as to effect economy in cost of purchasing and holding inventory. This Economic Order Quantity (EOQ) and the Number of Orders are determined mathematically as:

Inventory cost C = Ordering cost + Inventory carrying cost

$$C = C_o \div N + \{(C_i \div A)/2N\} \tag{i}$$

For cost to be minimum

$$\frac{dC}{dN} = C_o - \frac{C_i A}{2.N^2} = 0$$

$$N^2 = \frac{C_i A}{2.C_o} \text{ or } N = \sqrt{\frac{C_i \times A}{2C_o}} \tag{ii}$$

And

$$C = C_o N + \frac{C_i A}{2N} = \frac{1}{2N}(2C_o N^2 2 + C_i A) = \frac{2C_i A}{2N} \tag{iii}$$

Therefore, from (ii) and (iii)

$$\text{Least Inventory Cost} = \sqrt{2C_o C_i A}$$

And

$$\text{Economic Order Quantity (EOQ)} = Q = \frac{A}{PN} = \frac{1}{P}\sqrt{\frac{2C_o A}{C_i}}$$

The inventory cost corresponding to EOQ is shown in **Figure 8.2**.

$$
\begin{aligned}
\text{EOQ} &= \text{Economic Order Quantity} \\
C_o &= \text{Ordering Cost} \\
C_i &= \text{Carrying Cost} \\
\text{TC} &= \text{Total Inventory Cost}
\end{aligned}
$$

The Inventory Cost function, plotted in **Figure 8.3** is made up of Inventory Carrying Cost function and Ordering Cost function. The Inventory Carrying Cost (C) and Ordering Cost (Co) vary with the order Quantity (Q), but they move in opposite directions, i.e. when Q increases, C increases and Co decreases. The intersection point of these two functions indicates the Economic Order Quantity which results in least investment.

Example.   Take the case of stocking of 'an imported store' at a project site:
Site requirement = 480 tons spread uniformly over 6 months

> Ordering cost (Co) = $50/order Inventory carrying cost (Ci) = 25% of unit rate
> Unit rate (P) = $80 per ton
> Transporter capacity = 20 tons per trip

The Inventory cost corresponding to various demand patterns can be worked out as shown in **Table 8.5** and **Figure 8.3**. Therefore, the least inventory cost is $980 for 10 orders (EOQ) distributed uniformly in 6 months.

<div align="center">

Figure 8.2

Materials Inventory Cost Function

</div>

<div align="center">
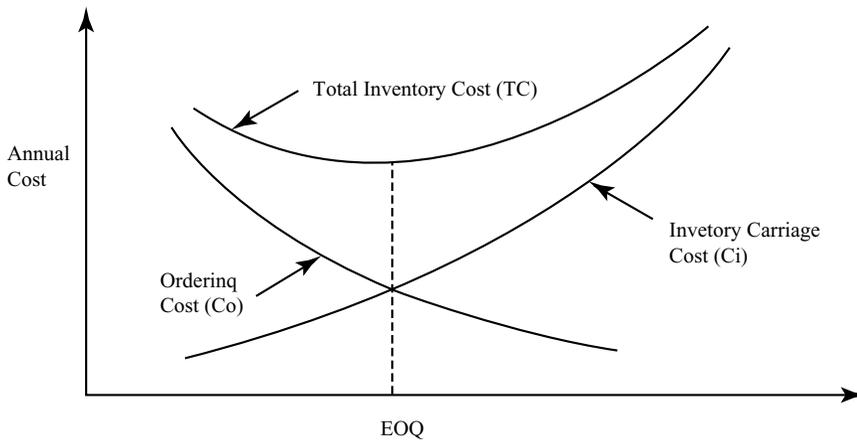
Figure 8.3

Repetitive Materials Inventory Cost Function Economic Order Quantity

</div>
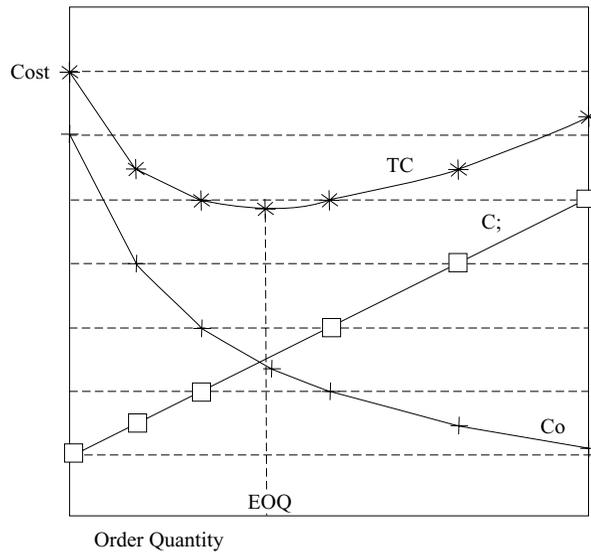
Factors affecting EOQ. The construction materials inventory differs from project to project. Considering that in a project, the required quantities of each material are known and assuming that the prices of frequently required items remain unchanged; factors affecting the inventory cost are C_o, C, N and A. Brief description of these is as follows:

1. C_o Ordering cost per order includes costs connected with ordering, such as clerical work for placing an order for delivery, follow-up using various communication channels, inspection on

Table 8.5

Inventory Cost Corresponding to Various Demand Pattern

Number of Orders N	Quantity per Order Q	(Tons) Average Q/2	Ordering Cost C_o N ($)	Carrying Cost C_i. P. Q/2 ($)	Inventory Cost C ($)
4	120	60	200	0.25 × 80 × 60	1400
6	80	40	300	0.25 × 80 × 40	1100
8	60	30	400	0.25 × 80 × 30	1000
10	48	24	500	0.25 × 80 × 24	980
12	40	20	600	0.25 × 80 × 20	1000
16	30	15	800	0.25 × 80 × 15	1100
20	24	12	1000	0.25 × 80 × 12	1240

where C_o = $ 50 per order

Note: Also refer to EOQ evaluation in Section 8.5.2. if the EOQ is made 20 tons and the supply orders are placed fortnightly then the inventory cost works out as $1000.

receipt, and the share of salaries of connected personnel. Co varies with the item source (local or imported) and the communication effectiveness between the purchasing department and the supplier's organisation. For all purposes, it can be assumed that the ordering cost per order is constant for a group of items having similar type characteristics or source of materials. For locally available items in particular, Co becomes negligible.

2. *C* Inventory carrying cost is expressed as a percentage of the unit price of the material. It comprises costs connected with interest on inventory investments, insurance, storage rental value, bins and racks, wastage, obsolesce, surplus disposal, and warehouse staffing expenses. For on-demand available items, C reduces with increase in number of orders.

3. *N* stands for the number of orders and it determines the corresponding quantity (Q) for each order. N depends upon the type of materials, which can be broadly divided into non- repetitive and repetitive materials.

   • For one-time order, non-repetitive materials, N = I and C becomes negligible if there is no stocking period; and
   • For repetitive materials, number of orders and quantity of economic order can be determined mathematically as explained above.

4. *A* denotes the project-material consumption or the usage cost. From the usage cost criteria, materials can be classified into A, B, and C categories. Alternately, using Pareto's Rule, materials can be grouped into High Value and Low Value. About 20% of high value items contribute to 80% of the usage cost and the remaining 80% low value items make up nearly 20% of the materials cost. Selective items inventory planning lays stress on planning of high value items.

❑ 8.5 INVENTORY PLANNING PROCESSES

8.5.1 Inventory Planning Approach

The construction materials inventory plan aims at evolving materials of stock-holding levels to meet project execution plan, with minimum inventory investment. If all the items with similar characteristics are stored under similar conditions and are procured from a similar source, then Co and Ci can generally, be considered as constant. However, in real life situations, Ci(percentage) is not constant for all types of materials, but varies with consumption value, the volumetric size of material as well as with storage type, while Co depends upon the location of the source. For these reasons, while planning inventory, materials with similar source and storage characteristics can be grouped together, and the Co and Ci for each group can be determined separately.

In a typical Housing Project, from the inventory point of view, construction materials can be classified as under, and their sub-grouping along with relevant factors affecting inventory cost is shown in **Table 8.6**.

Table 8.6

Factors Affecting Inventory Cost

S. No.	Materials Demand Pattern		Order Cost Per Order (C_o)	Carrying Cost Per Item (C_i)	Purchase Orders (N)
1.	Frequently Required High-Value Items				
	(a)	Local	Negligible	Item Type and Price	N = Maximum feasible
	(b)	Imported	Appreciable	"	$N = \sqrt{\dfrac{C_i.A}{2.C_o}}$
2.	One-Time Required High-Value Item				
	(a)	Local	Negligible	Negligible	N=1
	(b)	Imported	Fixed	"	N=1
3.	Minor Low-Value Items				
	(a)	Local	Negligible	Low	N= Maximum feasible
	(b)	Imported	Appreciable	"	N= Minimum feasible

Construction materials, listed in the above categories based on location of the supply source, can be further sub-divided into locally available materials and imported materials. These materials, from

storage considerations, can be further divided into, bulky and non-bulky items. It is also appropriate to consider lead-time for the supply of these materials. The approach for planning inventory for these groups of materials is outlined in subsequent paragraphs.

8.5.2 Planning Inventory of Repetitive Materials

The inventory planning for the repetitive construction materials involves determination of economic order quantity, fixing of maximum and minimum stock limits, lead time for stock replenishment and reordering point (ROP) for each item of, 'A' and 'B' category, construction materials, i.e. high value materials.

The basic simplified model of inventory replenishment pattern as shown in, **Figure 8.4** depicts the economic order quantity, working stock, the safety stock, the minimum stock level, the maximum stock level, and the number of replenishment or re-order points (ROP), during the usage period, for each item of material.

Figure 8.4

Inventory Replenishment Model
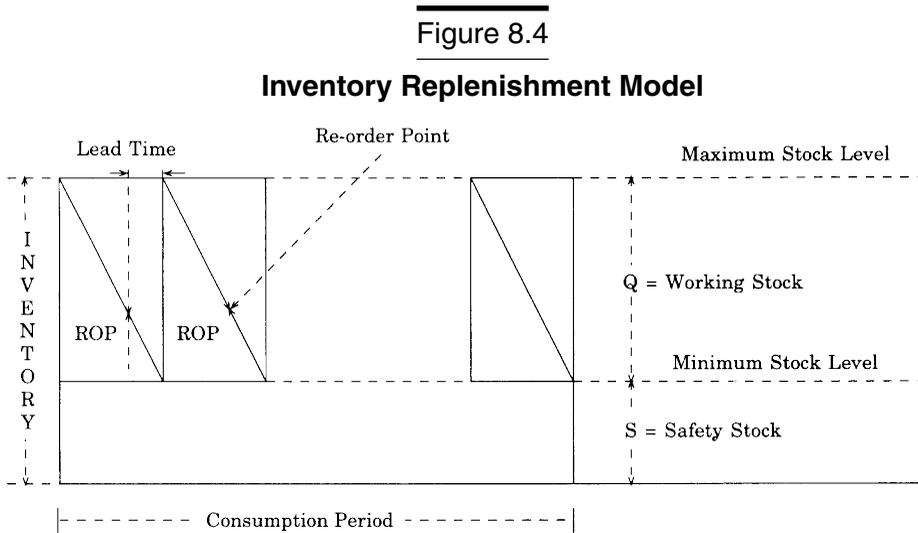
The inventory replenishment model shows the number of replenishment cycles during the usage period. The initial inventory of materials at the start of work consists of working stock (Q) and safety stock (S).

Consider the imported item example covered above. The number of orders (N) and inventory cost (C) can be determined as follows:

$$N = \sqrt{\frac{\{C_i A\}}{2C_o}} = \sqrt{\frac{0.25 \times \$80 \times 480 \text{tons}}{2 \times \$50}} = 10$$

$$C = \sqrt{\{2.C_o.C_i.A\}} = \sqrt{2 \times \$50 \times 0.25 \times \$80 \times 480 \text{tons}}$$

$$= \$980$$

Working stock.   It is equal to the normal consumption quantity during each cycle. Assuming the rate of consumption to be uniform in each cycle, it can be determined by dividing the total quantity required during the period with the number of cycles:

$$\text{Work stock} = Q, = \frac{\text{Total quantity during the period}}{\text{Number of replenishment cycles}}$$

Safety stock.   It is the floating stock that is held to cater for changes in rate of consumption, delays in delivery of materials from the agreed dates, and other unforeseen causes, so as to prevent stock-outs resulting in production hold-ups. The safety stock for a given situation can be determined using statistical techniques. Generally, a minimum safety stock can be taken as equal to consumption quantity in lead time period.

Lead time.   It is defined as the total time that is required for an item replenishment of material from the time an indent is submitted to the purchase department to the time ready for-use materials are received at the project stock-yard for storage or are delivered at the site of work.

Maximum stock level.   It can ideally be determined by adding working stock and safety stock, where the minimum stock level is generally taken equivalent to safety stock. The other factors considered for fixing maximum stock level, includes rate of materials' consumption, lead time to obtain new deliveries, risk of deterioration, storage space available, cost of storage, market fluctuations, seasonal considerations, and the funds earmarked.

Reorder level.   It is the level at which the stock is ordered. This is determined by adding assessed consumption during the lead time period to the minimum stock level.

Replenish level.   It is the desired level of inventory. The quantity to be ordered is determined with reference to this level. At the time of placing an order; the quantity to be ordered, the quantity already ordered but not received, and the quantity in hand, all sum up to this level. For example, take the case of stocking of cement at a project site:

Site requirement	=	500 tons/month for 12 months
Ordering cost (C_o)	=	$40/order
Inventory carrying cost (C_i)	=	20% of Inventory Value
Unit rate (P)	=	$100/ton
Transport capacity	=	20 tons
Lead time	=	5 working days
Safety stock	=	100 tons (approx. 5 days consumption)
Materials life	=	2 months.

Since, the daily consumption of cement is about 25 tons that is being replenished at the rate of 160 tons per week; the cement stock (maximum level 320 tons) gets rotated within two weeks, and hence its quality during storage is not affected. However, keep in consideration that stock at any

single point of time does not exceed 320 tons, i.e. maximum stock level. It may amount to stoppage of some orders in between.

Practical applications of repetitive inventory model: The simple model outlined above shows the relationship between Economic Order Quantity (Q) and the Number of Orders (N), involving least investment, for an item of material that is needed repeatedly during its usage. In its simplified version, it pre-supposes that materials are available freely, in any quantity, and at predetermined fixed prices. It also assumes that the usage schedule depicting requirements of materials is fairly accurate. In its presented form, the inventory model is deterministic in character, i.e. there are no fluctuations in requirement and price of materials with passage of time. The probabilistic model, which includes fluctuation in parameters, is not covered in this chapter.

The Inventory Cost function at EOQ point is nearly flat for a short range. This shows that the marginal change in EOQ quantity within this range does not appreciably, affect the total inventory cost. This EOQ flat range characteristic is used in practical applications as under:

1. Simplify the number of orders. For example, if N = 38, instead of ordering in an irregular manner, (At a frequency of 52/38 weeks) the orders can be placed thrice a month or weekly, and the quantity of order adjusted suitably, as per the actual situation.
2. Order in terms of standard lot supply. For example, if cement is being supplied in bulk of 20 ton capacity, then the order should be for multiples of 20 ton.
3. Order perishable quantities keeping their shelf-life in view, so as to prevent wastage due to deterioration in quality.
4. Adjust the order quantity in case of better discount offers, seasonal variation in prices, weather conditions and other similar causes.
5. Reduce the number of orders for low value 'C' category items, as these do not affect the overall inventory cost appreciably, provided the storage space permits.

Bulk items include raw materials and semi-finished bulky stores, such as soil, sand, aggregate, cement, lime, reinforcement steel, masonry blocks, timber, water, and other similar items, The common features of bulky items are that they occupy a large space and need extensive transportation facilities for their movement. Most of the bulky materials are frequently required over a long period of time. In particular, locally available bulk items can be replenished on a day-to-day basis and their procurement is planned in such a way that their stock position is kept within pre-determined minimum and maximum levels.

8.5.3 Planning Inventory of Non-Repetitive One-Time Purchase Materials

These are non-regular and mostly one-time purchased items of construction materials. These materials are purchased for a specific purpose, such as architectural fittings and fixtures, water supply and sanitation, HVAC and electrical and mechanical works, and moveable and fixed equipment like pumps and generating sets. It is important that non-repetitive materials must be inter-linked with

connected construction activities and specifications, and possibly, codified during the identification stage. In case of non-repetitive items, the aim should be to have a zero inventory prior to commencement of activity and after completion of the job, with low average during execution.

The requirement for non-repetitive items, which are mostly for one-time use, can be derived date-wise from the project plan, and these can be procured as and when required and need not be stocked for a long time provided market permits. In such cases, based on lead-time for procurement of materials, the delivery schedule can be easily worked out and supply orders can be placed, accordingly. The important consideration is that the materials of right quality and quantity from a right source should be negotiated for purchase well in advance and ad hoc purchase should be discouraged, as they generally cost 10%–15% more than the timely planned purchases.

Further, the procurement of non-repetitive materials should be properly scrutinised, so that no surplus material is left-over, after the activity is completed. However, it should be remembered that it is better to stock in advance, if there is a chance of non-availability in the market when these non-repetitive items are actually required.

8.5.4 Minor Materials Items Inventory

Minor materials consist of, low-cost, commonly use, and frequently needed stores or items for various construction activities. These stores include tradesmen tools and frequently used minor, indirect, regularly consumed materials like screws, nails, and cordage. The list of minor items held at warehouse site varies with project size. Typical stores are needed for mobilisation of building construction projects by a contractor at a remote location. The minor materials lists used by a construction corporate for small, medium, and large-size project are listed in **Exhibit 8.2**. The quantity of minor materials held at any point of time can be controlled by specifying minimum and maximum limits for each item.

❑ 8.6 APPLICATION OF VALUE ENGINEERING IN THE PROCUREMENT OF MATERIALS

8.6.1 What Is Value Engineering?

L. D. Miles, the founder of Value Analysis, defined Value Analysis as "an organised creative approach, which has the efficient identification of unnecessary cost, i.e. cost which provides neither quality, nor use, nor life, nor appearance, nor customer features." The five questions in value analysis process, propounded by L. D. Miles, are:

1. What is it? It implies defining the problem and components for the analysis.
2. What does it do? It means identifying the basic and secondary functions of the product.
3. What does it cost? It involves determining the cost of each function, component-wise.
4. What else will do the job? It aims at finding alternate solutions that perform the same or better function.
5. What does that cost? Its focus is to finding costs for alternatives that produce same or higher values.

Exhibit 8.2

Minor Materials Mobilisation Stock

S. No.	Item	Unit	Project Small	Medium	Large
	General Stores				
1.	Buckets (plastic)	Nos	2	4	6
2.	Petromax complete	Nos	2	4	4
3.	Glass for petromax	Nos	2	4	4
4.	Mantle for petromax	Nos	2	4	4
5.	Lantern complete	Nos	2	4	4
6.	Glass for lantern	Nos	2	4	4
7.	Torch (Battery) with cells	Nos	2	4	4
8.	Shuttering oil	Ltrs	50	50	100
9.	Spades (Hand showels)	Nos	10	12	16
10	Iron pans (Tasla)	Nos	10	12	16
11	Pick axe	Nos	10	12	16
12	Handles for pickaxe/ showels	Nos	6 each	6 each	8 each
13	Coir strings	Nos	6	10	12
14	Tile cutter (Electrical)	Nos	1	1	1
15	Wire mesh cutter Hammer	Nos	1	1	1
16	"1/2 Lb	Nos	-	-	2
17	"1 Lb	Nos	2	4	4
18	"1.1/2 Lb	Nos	4	6	10
19	"2 Lb	Nos	4	8	12
20	"10 Lb	Nos		2	4
21	"18 Lb	Nos	2	2	4
22	Screw driver (Assorted)	Nos	6	16	20
23	Spanner (sets)	Sets	4	6	8
24	Turn buckle	Nos	2	4	6
25	Files assorted	Sets	4	6	8
26	12" Hacksaw frame	Nos	2	4	6
27	Hacksaw blades	Nos	4	8	18
28	Adjustable spanner 8" and 12"	Nos	2 Each	4 Each	6 Each
29	Concrete chisel 10" long	Set	-	1	2

flat and pointed

30	Bolt threading die set	Set	1	1	2
31	Manila rope 1.1/2" Dia	Bundle	2	2	4
32	Nylon rope 3/4" Dia	Bundle	2	2	4
33	Screw 1" , 1.1/2" and 3" (144 Nos)	Pkt	20 Each	20 Each	20 Each
34	Wire nails 1" to 4" (144 Nos)	Pkt	20 Each	20 Each	20 Each
35	Steel nails 1" to 4"	Pkt	20 Each	20 Each	20 Each
36	Katoni. (nail beri)	Nos	2	4	6
37	GI washers	Nos	AS Required		
38	MS washers	Nos	"		
39	GI Pipes and fittings	Nos			
40	"1/2"	Nos	"		
41	"3/4"	Nos	"		
42	"1"	Nos	"		
43	Crow Bars 4" × 1"	Nos	1	1	1
44	Crow bars	Nos	1 Each	1 Each	2 Each
45	Nuts of various diameters	Nos		As Required	
46	Bolts of various dia/sizes	Nos	"		
47	GI buckets 5 Ltrs	Nos.	4	6	8
48	GI buckets 12 Ltrs	Nos	4	6	8
49	Wire brush	Nos	6	12	20
50	Ladders (aluminum)	Nos	4	4	8
51	Sand paper (fine to rough)	Dozen	4	6	8
52	Cotton waste	Kg	8	10	16
53	Water level pipe	Nos	2	4	4
54	Slump cone	Nos	1	1	1
55	Cube moulds	Nos	6	6	18
56	Jute cloth	Bundle	1	1	2
57	Plywood 4/6/12/18 mm	-		As Required	
58	Assorted softwood/hard wood for shuttering	-	"		
59	Wooden pegs	Nos	50	100	200
60	Steel rods for marking	Nos	50	100	100
61	Masking tape 2"/3"/4"	Roll	8 Each	8 Each	12 Each
62	Hard hat (safety hat)	Nos	10	20	40

63	Measuring tape steel 3 M	Nos	8	12	20
64	Measuring tape steel 5 M	Nos	2	4	6
65	Measuring tape steel 30 M	Nos	1	2	2
	Masons Tools				
1	Gum boots	Pairs	6	6	12
2	Aluminum float 4'or 6'	Nos	8	12	16
3	3'-4" Wide wooden float	Nos	4	6	8
4	2'-3" Wide wooden float	Nos	4	6	8
5	1'-2" Wide wooden float	Nos	4	6	8
6	Right angles	Nos	6	10	12
7	Plumb bob	Nos	6	10	12
8	Spirit level 2'/3'/4'	Nos	2 Each	3 Each	4 Each
9	Mason trowel (big, small)	Nos	3 Each	4 Each	6 Each
10	Sponge	Nos	10	10	18
11	Hand gloves	Pairs	20	20	30
12	Steel Gurmala	Nos	4	6	8
	Carpenters Tools				
1	Planner	Nos	4	6	8
2	Carpenters chisels 1/4" to 2"	Set	4	6	8
3	Sharpening stone for chisels	Nos	1	2	2
4	Glass cutter	Nos	1	1	1
5	Carpenters right angle	Nos	6	10	18
6	Carpenters pencil	Doz	2	4	6
7	Carpenters hammer	Nos	6	10	18
8	Carpenters woodsaw 12"	Ltrs	4	4	4
9	Carpenters woodsaw 18"	Nos	4	8	8
10	Carpenters woodsaw 24"	Nos	4	4	4
11	Carpenters vice	Nos	1	2	4
	Steel Fitters Tools				
1	Bar bendering keys	Nos	1 Each	1 Each	1 Each
2	Cutting pliers	Nos	6	12	30
3	Binding wire	As Required			
4	Steel bending die	Nos	2	4	4
	Painters stores				
1	Tyrolene M/C	Nos	2	2	4

2	Painting brush 2" and 4"	Nos	12 Each	24 Each	24 Each
3	Paint roller 9"	Nos	6	12	12
4	Paint tray	Nos	6	12	12
5	Paint thinner	Ltrs	20	40	80
	Welders Tools				
1	Hand gloves for welding	Nos	1	1	2
2	Screen glass	Nos	1	1	2
3	Welding rods	Pkts	2	2	4
4	Welding set	Set	1	1	1
5	Gas nozzles	Nos	1	1	2
6	Nozzle cleaner set	Nos	1	1	2
	Plumber Stores				
1	Die set 1/2" to 1.1/2"	Set	1	1	1
2	Pipe cutter	Nos	-	1	2
3	Chain spanner	Nos	-	1	2
4	Table vice	Nos	-	1	2
5	Pipe wrench 10"/14"/18"	Nos	1	1	2
6	Blow lamp	Nos	1 Each	1 Each	2 Each
7	Jute for plumber	Nos	1	1	2
8	Tape	Rolls	20	40	40
	Electrician tools				
1	Screw driver (assorted)	Nos	4	10	20
2	Insulation tape	Rolls	2 Doz	6	18 Doz
3	Flexible wire	Rolls	4	10	20
4	Lamp holders	Nos	10	20	40
5	Bulbs	Nos	20	40	80
6	Tube light fittings	Nos	4	12	36
7	Fluorescent tube 4'	Nos	4	12	36
8	Starters for tubes	Nos	4	12	36
9	Switches	Nos	24	48	96
10	Knife	Nos	1	2	4
11	Insulated nose plier	Nos	1	2	4
12	Insulated cutting plier	Nos	1	2	4
13	Multimeter	Nos	-	1	2
	Admin. Materials				

1	Flying insets killer	Tins	4	4	6
2	First aid box	Set	1	4	4
3	Toilet cleaning chemical	Tins	4	4	4
4	Sweep brush (long handle)	Nos	4	6	12
5	Sweep brush (small handle)	Nos	4	6	12
6	Cotton caps	Nos	40	80	150
7	Trash bags	Nos	40	80	150

With the passage of time, the value analysis practitioners have modified the discipline and process of Value Analysis to fit their requirements. In 1954, the U.S. Navy Bureau of Ships applied the Value Analysis process to cost improvement during design. They called it 'Value Engineering'. Some refer this as 'Value Management'. In the Construction industry, it is generally called 'Value Engineering'.

In broader context, 'Value Engineering', as a discipline comprise a series of techniques that are aimed at an organised systematic effort directed at analysing the function(s) of items, products, equipment, processes, and procedures, for the purpose of accomplishing all the required functions at the lowest total cost. This cost covers not only initial cost but also ownership cost covering operation/maintenance, disposal costs etc., throughout the desired or specified life cycle of the articles or subject under study.

Value Engineering is the systematic application of recognised techniques by multi-disciplined team(s), which identifies function of a product or service; establish a worth for that function; generate alternatives through the use of creative thinking; and provides the needed function reliably at the lowest cost. The process of Value Engineering involves, function orientation, organised approach and creative thinking; having the basic equation, that is:

$$\text{Value} = \text{Worth/Cost}$$

Function orientation. The value of a product or service is the worth for the function(s) it performs and the cost allocated for performing the function(s). The term 'function' is used to mean the purpose or use of a product. Thus, to measure worth, the product or process is first translated into the functions. Cost is also not simply the initial price but must also include follow-on costs during the life cycle of the product.

Creative thinking. The value of a product can further be divided into following categories:

1. *Basic Value*: The properties and qualities, which accomplish a useful purpose or service.
2. *Esteem Value*: The properties, features or attractiveness, which cause a customer to want or own it.
3. *Cost value*: The cost of labour, material and various other expenses required to produce it.
4. *Exchange Value*: The properties or qualities that enable us to exchange it for something else we want.

The value of a product can be increased by:

- Improving the functional utility without change in cost;
- Retaining the same functions for less cost; and
- Combining improved functional utility with less cost.

Both, Value Engineering and Cost Reduction, aim at reducing costs but there is a basic difference between these techniques. Value Engineering is function–oriented, whereas Cost Reduction is production oriented. Value Engineering aims at functional cost effectiveness by avoiding unnecessary costs; it involves multi-discipline team effort; and applies innovative and creative techniques to maximise value. On the other hand Cost Reduction, aims at changing the method of production to reduce the production cost of an item, it involves usually an individual effort and generally, its emphasis is on analysis of the past practices and processes to reduce costs.

8.6.2   Value Analysis Job Plan

The Value Engineering job plan attempts to generate, identify, and formulate the best value alternative for making specific recommendations supported with proper data and identifying the actions necessary for its implementation. Miles' system followed a rigorous six-step procedure, which he called the Value Analysis Job Plan, for conducting the studies. Others have varied the Job Plan to fit their peculiar constraints. A modern version has the following steps:

1. **Planning and organisation**. The main aspects considered during the planning and organisation phase are: the study objectives, the composition of the study team, information on which to base the study, and designing the organisation for the study.
2. **Information gathering**. The information needed will vary widely, depending on the type of objective that needs to be accomplished. The detailed information requirements for the project are, identified and distributed to team members.
3. **Functions and costs identification**. After identification, these are tabulated in a matrix format.
4. **Development of ideas and means for solution**. In this creative phase, alternative methods and better ways of doing things are explored.
5. **Study and evaluation of solutions**. A number of techniques are used to identify the best ideas and prioritise them in terms of cost, time, and practicality.
6. **Appraisal of proposed solutions**. During this phase, developed initiatives are formally presented to senior management along with the alternatives and appropriate financial analysis, where investment is required.
7. **Implementation phase**. During this phase, selected proposals are implemented and new approaches are brought into practice.
8. **Follow up after implementation**. It is essential that implemented proposals are systematically followed up to ensure that full benefits are achieved.

8.6.3   How Is Function Analysed?

Value Engineering is unique in manner as its focus is on the functions analysis of the product or a service or a system with a view to find out alternative way to provide the prescribed function at a lower cost without sacrificing the required performance standards. Core of the Value Engineering is the Function Analysis. Functional Analysis is a process, which involves identification of the functions, costing of functions, and then analysing the functions to achieve the required objective economically.

Identification of functions.   Each product or process under study is identified in terms of the functions it performs. Each function is designated using two words, that is, verb followed by noun. Each noun is ideally a parameter or measurable quantity. For example, the functions of the components in a lead pencil perform functions, like protecting wood remove marks, erase writing, improve look, make marks, transmit force, display information, support lead, and protect wood. In short, these two-word function statements are a total description of the product or process. The total number of these functions could run from forty to eighty for even a simple product or process. The functions are divided into two categories i.e. basic functions and secondary functions. The basic functions mark the principle reasons for the existence of the product; whereas, the secondary functions become necessary to support the primary function(s). In the example of the lead pencil, the primary function is to make marks, which can be erased and all other functions identified above are secondary functions.

Costing of functions.   The next step is to cost these word-pair functions. Take the example of production of a Lead Pencil. The problem is to develop a new Lead Pencil at an acceptable cost for common use. The market analysis reveals that the maximum retail price of such a pencil can be around Rs. 10.00 and its target production cost must not exceed Rs. 5.00. The functions of a pencil identified with the function category and the cost are tabulated in function-cost matrix given in **Table 8.7**.

In value analysis, the accent is on function, which a component is required to perform and not on the component itself. Accordingly, the cost relates to the functions rather than the product. When a component serves one function, the cost of the component is equal to the cost of the function. However, in some cases, if a component serves more than one function, then the cost of the item is apportioned within the related functions.

Analysing the functions.   The functions in order of their cost are then selected for value analysis. The value analysis involves application of different techniques in order to achieve the required objective. It also includes qualitative questioning method and the analytical optimisation techniques to achieve the function, economically. The qualitative function analysis method includes the option of elimination, modification, substitution, combination, and innovation etc,, whereas analytical methods are mostly employed for minimisation and optimisation of functions.

Table 8.7

Function–Cost matrix

Functions	Remove marks	Erase writing	Improve look	Make marks	Transmit force	Display info	Support lead	Protect wood
Functions category	Second.	Second.	Second.	Basic	Second.	Second.	Second.	Second.
	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost
Component Cost (Rs.)								
Lead 1.20				1.20				
Body 1.00					0.50	0.10	0.4	
Paint 1.00			0.50					0.5
Eraser 2.80	2.80							
Metal band 1.00		0.50	0.25		0.25			
Total Rs. 7.00	2.80	0.50	0.75	1.20	0.75	0.10	0.4	0.5
Total Cost %	**40%**	**7.1%**	**10.6%**	**17.0%**	**10.6%**	**1.5%**	**6.0%**	**7.1%**

One of the techniques often been used in value analysis is the 'Functional Analysis System Technique' (FACT). This technique identifies a basic function and models its relationships with higher and lower level functions by asking 'HOW' functions are performed and testing validity by asking 'WHY' functions are performed. The FACT methodology uses both structured and creative techniques, to develop alternative ways for performing necessary functions at lowest overall cost without degrading quality or performance. Services of a Value Engineering professional are invaluable for analysing the functions.

8.6.4 Create Value Analysis Awareness

Value analysis awareness can be created by subjecting each material procurement order to the following checklist:

a. *Eliminate*. If the function does not add anything desirable to the end product.
b. *Alternate*. Explore the better or cheaper alternatives.
c. *Standardisation*. If the component performing functions is a non-standard; locate a standard item that serves the purpose at cheaper rates.
d. *Modification*. If the item cost is not reasonable in terms of its function to the end- product or end-operation, try modification, substitution, or combination of other functions to make it cheaper.

e. *Consumption reduction*. Analyse the process to explore, if the consumption of the item can be cut down by Value analysis.
f. *Redesigning component*. If the specifications and tolerances are too complex. If the method of manufacturing is cheaper and trouble free.
g. *Make decision*. Analysis of reasonable cost of material, labour, over-heads, and reasonable profit roughly equals the quoted price. If not, further investigation is needed. Also examine part buy or buy unfinished parts and finish at your works or vice-versa.
h. *Supply source*. Locate another dependable source supply at a lesser price or better material at the same price, if the present source of supply is not the best.
i. *Imported components*. Can you do without it? If not, is it possible to obtain it from indigenous sources

With practice, the value analysts will be able to draw up a questionnaire for the use of the procurement cell in each project and revise it from time to time.

8.6.5 Organising Value Engineering Function in a Major Project

Value analysis as a staff function, can be entrusted to either technical manager, material manager, or planning manager. Since, Value Analysis needs inter-departmental cooperation at all levels for the success, Planning Chief, who performs the role of the project coordinator, can perform the value analysis function as he works in close conjunction with engineering, design, production, and purchase departments. If the project is large, it may be worth to appoint an independent value engineer working directly under project manager. Irrespective of the position or the type of organisation chosen, the Value Engineer must be a part of the project management team.

8.6.6 Scope for Application of Value Engineering in the Procurement of Materials

Value Engineering is an important tool of materials management. There is virtually no group of materials or service which cannot be value-analysed. In project environments, where the designs are finalised before the starting the project, there is great scope for value analysis in the materials procurement phase. Some of commonly used project materials, which can be value-analysed, are:

1. Select materials of A (high usage value) and B (medium usage value) as categories for Value Engineering. Even a small percentage of reduction, after Value Analysis, for an A item will mean substantial reduction in over-all costs.
2. Select materials whose quality, prices, and deliveries are not favourable. Value Analysis can aid in finding substitutes, which can be obtained from other sources.
3. Select materials being imported. Value Analysis can assist in locating domestic substitutes.

8.7   USE OF OPERATIONS RESEARCH IN MATERIALS PLANNING

Operations research is the application of scientific methods, techniques, and tools, involving the system operation that provides optimum solution for making effective decisions. The techniques of Operations Research are used to solve problems relating to resource allocations, transportation, queuing, waiting time, sequencing, inventory control, and equipment replacement. These techniques can be usefully employed to plan procurement of materials. The Linear programming technique applications used for solving resource allocation, minimising transportation costs, and maximising contribution, are given in **Appendix H**.

In brief, it is desirable that the engineers involved in planning of materials should work on the problems that require solutions by the applications of operation research and other analytic methods. If necessary, assistance of the operations research experts may be sought to make decisions.

APPENDIX H

Resources Allocation
Using Linear Programming

❑ H.1   INTRODUCTION AND SCOPE

Resources allocation aims at allocation of limited resources, such as manpower, materials, machinery and money, among number of competing organisations or groups, within specified constraints. In problems related to resources allocation, we determine allocation, which optimises the total effectiveness. The resources allocation problem has certain common features. These are characterised by the presence of a number of variables, each of which can assume values within a specified range. These variables have certain associated constraints. The analysis of allocation situations / constraints, which can be formulated in terms of linear algebraic equations, is called Linear Programming.

The main objective of solving resources allocation problems, using Linear Programming (LP) is to optimise the total effectiveness, such as minimising costs of resources or maximising profit/ contribution. The emphasis is on understanding of the method of how the LP mathematical models are formulated and how to solve the problems, using the commonly available software like Excel with Solver aid-in. There are also many other methods for solving time consuming LP problems, such as graphical, simplex, duel etc.; however, these are not covered in this Appendix.

❑ H.2   PROBLEM SOLVING APPROACH ILLUSTRATED WITH AN EXAMPLE

Linear Programming technique is applicable to problems in case, where, the total effectiveness is expressed as linear functions of individual allocation and the limitations of resources constraints. This enables conversion of objectives to a linear decision variable and the constraints to linear inequalities. The problem, thus, reduces to maximising or minimising of a linear function subject to a number of linear inequalities.

After the allocation problem is conceptualised the solution involves the following steps:

1. Formulation of the Problem:

   - Decide the variables to be optimised;
   - Define the objective function (Z); and
   - Set up constraints equations

2. Develop the Mathematical Model.
3. Use MS-Excel Solver, 2007 to determine values of variables that optimise effectiveness.

The basic approach in solving the Linear Programming problems is explained with a simple example. For in-depth study, Readers may refer to standard books on Operations Research.

H.2.1   Formulation of the Problem

The first step in solving Linear Programming problems is to recognise the existence of an allocation problem and to formulate it into a statement for mathematically resolving the problem.

Sample Problem.   Consider, as a gravel production company that operates two pits, producing different mixes of sand and gravel. After computing the output, it is separated into three grades. A construction company has entered into a contract with the sand and gravel production company, to take 120 tons of fine grade, 80 tons of medium grade, and 240 tons of coarse grade per week. Cost of sand and gravel production is $20 per hour to operate one pit and $25 per hour to operate the other. In 8 hours per day operation, the first pit produces 20 tons fine, 20 tons medium, and 120 tons coarse material. The second pit produces 60 tons of fine, 20 tons of medium, and 40 tons of coarse material.

The problem is to determine the number of hours each pit be operated by the production company in order to meet the weekly requirements in an economic manner, that is, to minimise the operating cost of production pits?

H.2.2   Construction of Mathematical Model

It involves deciding the variables used in the optimisation problem, developing the objective function (Z), translating the specified constraints into algebraic equations, and analysing the mathematical model.

Decide the variables.   In the given problem, let the two pits be named as A and B and let x1 and x2 be the operating times in hours per week respectively.

Defining objective function (Z).   The weekly operation cost of these pits can be worked out as under:

Name of pit	Hourly production cost	Weekly production time	Weekly production cost
Pit A	$20 per hour	x_1 hours	$20x_1$
Pit B	$25 per hour	x_2 hours	$25x_2$

Therefore, the total cost of operations per week for both the pits is equal to $20x_1 + 25x_2$

Let Z be the objective function. Hence, to economise on operation cost of pits, we must aim at:

$$\text{Minimising operating cost}\quad Z = 20x_1 + 25x_2$$

Where, x_1 and x_2 are the decision variables.

Setting up technical specifications.   In this case, the sand and gravel company has undertaken to supply 120 tons of fine grade, 80 tons of medium grade, and 240 tons of coarse grade, per week. Since it is a contractual requirement, the supply must not be less than this quality.

a.   **Fine grade requirement**. The operation of pit yields the following quantities of fine grade:

Name of pit	Quantity of production per 8 hours	No. of hours run per week	Production per week
Pit A	20 tons	x1	20/8 × x1
Pit B	60 tons	x2	60/8 × x2

Therefore, total production of fine grade per week is $20/8x_1 + 60/8x_2$.

Since, the supply to be made is 120 tons, which is a contractual requirement, the production must not be less than 120 tons; it can be equal to or more than this subject to optimisation of operation time. This constraint can be expressed algebraically, as:

$$20/8x_1 + 60/8x_2 > 120, \quad \text{or} \quad 20x_1 + 60x_2 > 960, \quad \text{or}$$

$$\text{For fine grade}\quad x_1 + 3x_2 > 48$$

b.   **Medium and coarse grades**. Proceeding similarly, we can express the constraints on medium and coarse grade production in the form of the following inequalities:

$$\text{For medium grade}\quad x_1 + x_2 > 32$$
$$\text{For coarse grade}\quad 3x_1 + x_2 > 48$$

c.   **Operating time**. Each pit can be operated for 8 hours per day. Assuming that there are maximum 6 working days in a week and no overtime is permissible, then the total operating time

per pit can be expressed as:

$$\text{For pit A} \quad 0 < x_1 < 48$$
$$\text{For pit B} \quad 0 < x_2 < 48$$

H.2.3 Developing Mathematical Model

The problem is to find out operating time x_1 and x_2 in hours to minimise operating cost. It can now be stated in a mathematical model as:

- Minimise operating cost

$$Z = 20x_1 + 25x_2$$

Where, x1 and x2 in hours are the decision variables.

- Subject to:

$$x_1 + 3x_2 > 48$$
$$x_1 + x_2 > 32$$
$$3x_1 + x_2 > 48$$
$$0 < x_1 < 48$$
$$0 < x_2 < 48$$

H.2.4 Determination of Optimum Solution of the Model using Excel-Solver Software

The given problem contains two decision variables. Such problem can be solved by various methods like graphical, simplex, duel, and computer programme. There are easily-available software programme like Excel-Solver that can simplify solutions. The procedure for solving the LP mathematical model using Excel-Solver Software for the sand and gravel production company problem is explained as follows:

1. Open MS Office 2007/Excel/Add-in/Solver. Type mathematical model data, is inserted, as shown below in **Figure H.1**.
2. Click Data/Solver icon in toolbar to see the solution of the Model as reproduced below in **Figure H.2**:

Answer:

The operating for economical operation for each pit works out as under

- Pit A = 24 hours
- Pit B = 8 hours

Minimum operating cost per week = $680

3. Explanatory Notes, shown in **Figure H.2**:

Figure H.1
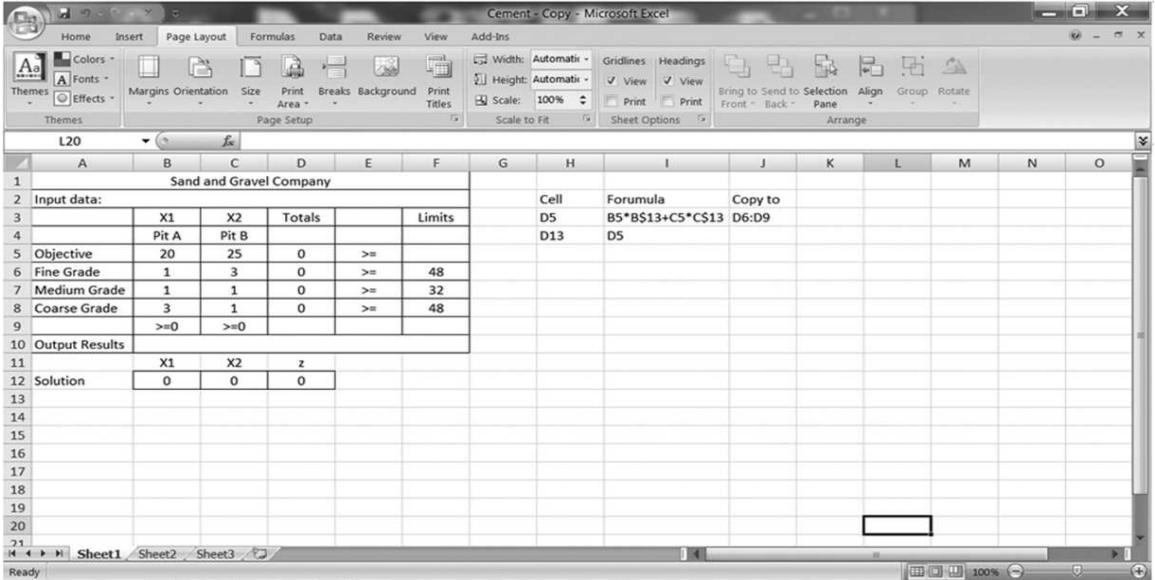
Figure H.2
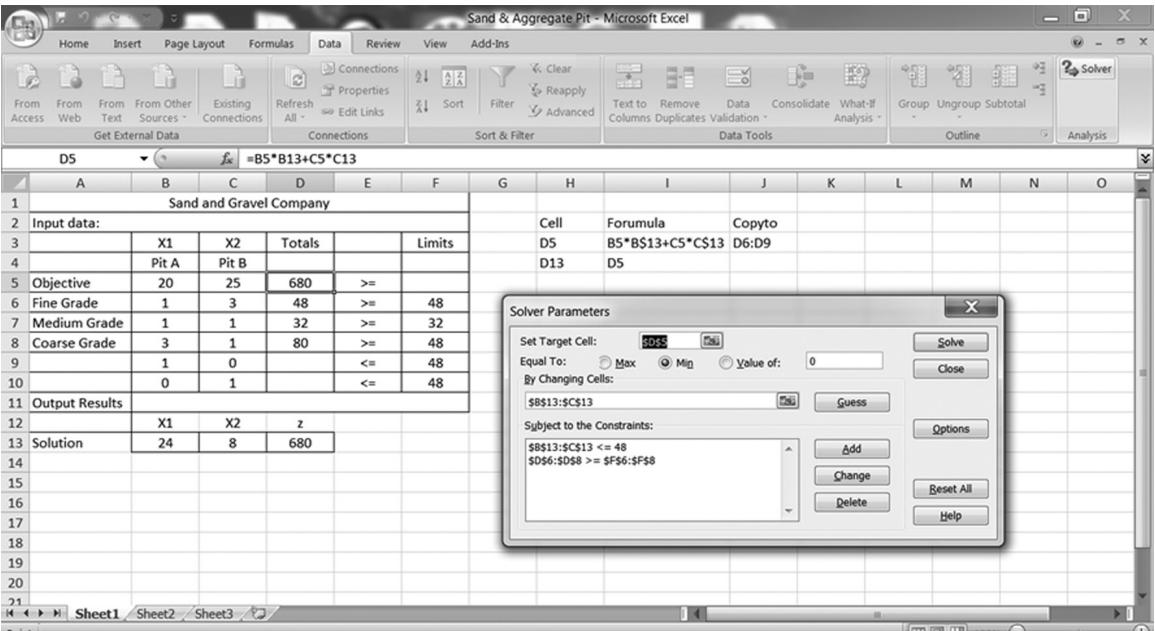
- Spread sheet is the input and output media for LP problems;
- **Figure H.2** shows the layout of the input data of decision variables, objective function, constraint equations and all values of all the outputs.
- Use layout format for data incorporation;
- Enter the formula for D5 and then copy it into cell D6:D9. Note for large size variables
- (> 3), enter = SUMPRODUCT(B5:C5, B3.5C1.3) and type format;
- From Excel Toolbar, click 'Solver' to open solver parameters dialogue box; first set object function, and then perform data optimisation; and
- Set target, click optimisation criteria, and finally, click Solver (right last icon in tool bar) to see the **Figure H.2** layout output data with dialogue box.

❑ H.3 TYPICAL SOLVED EXAMPLES USING EXCEL SOLVER SOFTWARE

H.3.1 Two Variable Contribution Maximisation

A company produces two products, A and B. The contribution for product A is $10 and product B is $6. The hours required to produce one unit of each product, at each of two factories C and D, are shown in the following table:

Factory Product	C	D
A	12	4
B	4	8

There are 60 hours available at factory C and 40 hours at factory D. Determine, the optimum product mix and the resulting maximum contribution.

Solutions:

Developing Mathematical Model. The problem is to find out the operating product mix of x_1 and x_2 to maximise contribution. It can now be stated in a mathematical model as:

- Maximise

$$Z = 10x_1 + 6x_2$$

Where, x_1 and x_2 are the decision variables.

- Subject to:

$$\begin{aligned} Factory\ C \quad & 12x_1 + 4x_2 < 60 \\ Factory\ D \quad & 4x_1 + 8x_2 < 40 \\ & x_1 > 0 \\ & x_2 > 0 \end{aligned}$$

Using MS-Excel Solver, 2007

Answer:

Optimum product mix: Product A = x_1 = 4
                        Product B = x_2 = 3
Resulting maximum contribution $Z = 10x_1 + 6x_2$ = \$58

H.3.2 Two Variables Leading to Maximising Profits in Manufacturing

A company makes two types of leather belts—A and B. Belt A is of high quality and Belt B is that of lower quality. The respective profits are \$0.40 and \$0.30 per belt. Each belt of type A requires twice as much time required type B belt. However, if all belts were of type B, the company could make 100 belts per day. The supply of leather is sufficient for 800 belts per day (for both A and B combined). Belt A requires a fancy buckle and only 400 per day are available. While for Belt B, only 700 buckles are available. Find the number of belts for each type in which the company should make the maximum profits. Calculate also the maximum profit.

Solutions:

Developing Mathematical Model. The problem is to find out the number of belts for each type so that the company should make the maximum profits.

Let x_1 and x_2 be the number of belts of each type with each making profit of \$0.40 and \$0.30 per belt respectively. Then the mathematical model for maximising profit can be stated as:

- Maximise profit

$$Z = 0.4x_1 + 0.3x_2$$

Where, x_1 and x_2 are the decision variables.

- Subject to:

$$
\begin{aligned}
\text{Time constraint} \quad & 2x_1 + x_2 < 1000 \\
\text{Leather constraint} \quad & x_1 + x_2 < 800 \\
\text{Fancy buckle Belt A} \quad & x_1 < 400 \\
\text{Buckle for Belt B} \quad & x_2 < 700 \\
& x_1 > 0 \\
& x_2 > 0
\end{aligned}
$$

Answer:

1. For maximum profits, make the following the number of belts for each type:

Using MS-Excel Solver, 2007

- Belt A is of high quality $x_1 = 400$
- Belt B is that of lower quality $x_2 = 400$

2. Maximum profit $= 0.4 \times 400 + 0.3 \times 400 = 280$

H.3.3   Two Variable Minimising Total Delivery Cost

A transport company has to deliver 4800 boxes of product A and 3600 boxes of product B, to a customer. The company has two types of trucks: T1 and T2 at its disposal. The capacity of truck T1 is 600 boxes of product A and 900 boxes of product B; while, that of truck T2 is 600 boxes of product A and 300 boxes of product B.

The object is to minimise total delivery cost, where the relevant costs of T1 and T2 truck are $150 and $100, respectively. How many trucks of each type should company use? What is the minimum cost?

Solution:

Developing Mathematical Model.   The problem is to find out the type and number of truck which the company uses to minimise delivery cost. Where, x_1 and x_2 are truck T1 and T2 (the decision variables) respectively.

It can be stated in a mathematical model as:

- Minimise deliver cost objective

$$Z = 150x_1 + 100x_2$$

Subject to:

$$
\begin{array}{ll}
\text{For Product A} & 600x_1 + 600x_2 > 4800 \\
\text{Or, for Product A} & x_1 + x_2 > 8 \\
\text{For Product B} & 900x_1 + 300x_2 > 3600 \\
\text{Or, for Product B} & 3x_1 + x_2 > 12 \\
& x_1 > 0 \\
& x_2 > 0
\end{array}
$$

Therefore,

$$\text{Minimise} \quad Z = 150x_1 + 100x_2$$

- Subject to:

$$
\begin{array}{l}
3x_1 + x_2 > 12 \\
x_1 + x_2 > 8
\end{array}
$$

Answer:

The object is to minimise total delivery cost, where the relevant delivery costs of T1 and T2 are Rs. 150 and Rs. 100, respectively. How many trucks of each type should company use? T1 $= 2$ and T2 $= 6$.

$$\text{Minimum delivery cost} = 2 \times 150 + 6 \times 100 = \$900$$

Using MS-Excel Solver, 2007
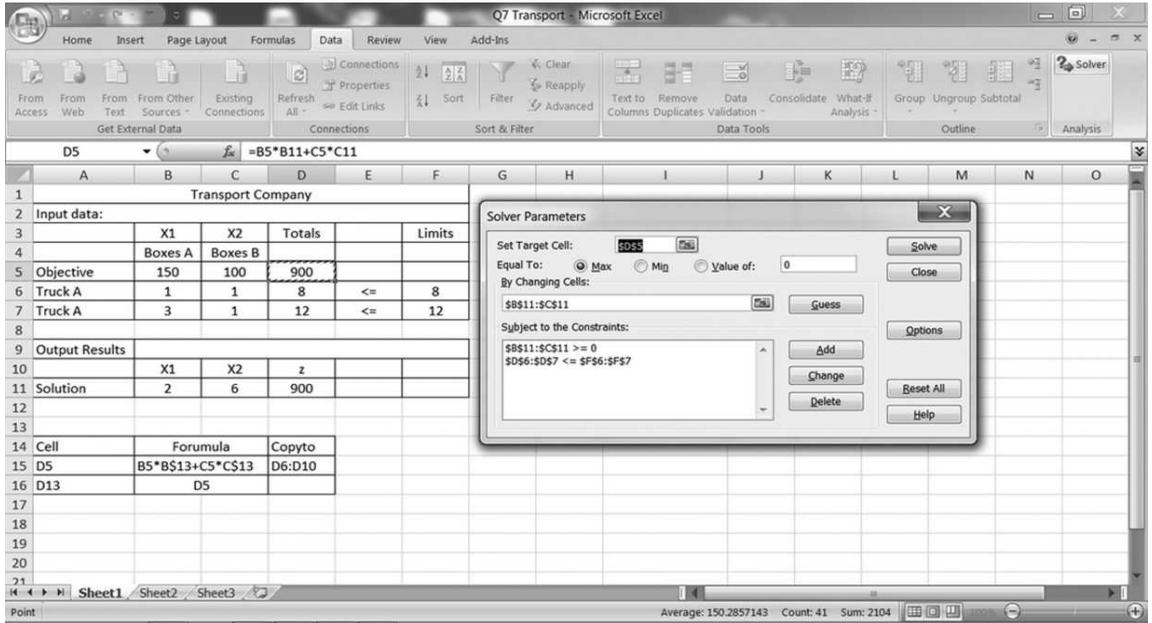
H.3.4 Three Variables Machines Purchase to Maximise Daily Output

A company wants to purchase three types of machines: A, B and C, where the amount of funds and space allocated to this machine investment should not exceed 30 000, since the number of employee available is limited.

Machine A costs Rs. 8000 and occupies 30 sq. ft. Machine B costs Rs. 13 000 and occupies 60 sq. ft. Machine C costs Rs. 15 000 and occupies 60 sq. ft. If machine A, B and C process 70, 90, and 126 pieces per day respectively, how many of each machine should company purchase to maximise its daily output. What is daily maximum output?

Solutions:

Developing Mathematical Model. The problem is to find out how many machines should company purchase to maximise its daily output and what is daily maximum output?

Let x_1, x_2 and x_3 be the number of machines of types A, B and C to be purchased.

The daily output of these machines works out as under:

Type of machine	Rate of output per day	No. of machines	Total output per day
A	70	x_1	$70\,x_1$
B	90	x_2	$90\,x_2$
C	126	x_3	$126\,x_3$

The object is to maximise daily output

$$Z = 70x_1 + 90x_2 + 126x_3$$

Development of technical specification/constraint

Type of constraints	Machine x_1	Machine x_2	Machine x_3	Constraint
No. of Machines	x_1	x_2	x_3	<30
Funds	$8000 \times x_1$	$13000 \times x_2$	$15000 \times x_3$	<400 000
Space	$30x_1$	$60x_2$	$60x_3$	1500

The above data leads to the following constraints:

$$x_1 + x_2 + x3 < 30$$
$$8x_1 + 13x_2 + 15x_3 < 400$$
$$x_1 + 2x_2 + 2x_3 < 50$$

Answer:

How many of each machine should company purchase to maximise its daily output.

$$x_1 = 10$$
$$x_2 = 20$$
$$x_3 = 0$$

Using MS-Excel Solver, 2007

What is daily maximum output?

$$Z = 70 \times 10 + 90 \times 20 + 126 \times 0. = \$2500$$

❑ H.4 CONCLUSION

Linear programming is a technique for optimising the allocation of resources within the specified constraints. Linear programming guarantees an optimal solution, provided that two main conditions are met. First, the constraints must be strictly linear and second, the variables must be non-negative. Some linear programming problems have simple structures and can be solved by using transportation and assignment techniques (not covered in the above text). However, the main skill in solving allocation problems using linear programming lies in the formulation of a mathematical model, as the solution of mathematical models can be easily obtained, using computers having suitable software. Readers should refer to standard books on Operations Research for in-depth study of allocation problems.

Project Construction Equipment

Construction equipment plays a significant role in the execution of modem, high-cost, and time bound construction projects. An indispensable item of resources, construction equipment produces output at high speed and enables completion of tasks in a limited time. Equipment saves manpower, a source, which is becoming scarce, costly, and more demanding day-by-day. Moreover, equipment improves productivity, quality, and safety.

The nature of production tasks, which can be performed with an equipment, includes excavating, hauling, transporting, compacting, grading, hoisting, concreting, pre-casting, plastering, finishing, trenching, pipe-laying, cable-laying, and so on. In addition, the support equipment at the project site consists of generators, pumping sets, treatment plants, and other utility services equipment. Construction equipment planning aims at identifying the construction equipment for executing project tasks, assessing performance capability of equipment, forecasting the date-wise requirement of equipment's numbers and types, and finally participating in the selection of the equipment to be acquired.

This chapter outlines the commonly used construction equipment. Moreover, the chapter also introduces the suitability of equipment for executing various tasks. Next, it describes the approach generally followed for assessing the ideal output of the equipment. Then, this ideal output is multiplied by the correction factors and the equipment performance factor (operating condition) to derive the output planning data of the equipment. This data planning is considered during the project-planning stage, with a view to forecast equipment requirement.

The subject covered in this chapter is divided into the following sections:

1. Classification of Major Equipment
2. Earth Factor in Earthwork
3. Earth Excavating Equipment
4. Earth Cutting and Hauling Equipment
5. Earth Compacting and Grading Equipment

6. Concreting Plant and Equipment
7. Cranes for Materials Handling

The earthwork equipment output planning data is tabulated at the end of this chapter in **Appendix I**.

The criteria governing the selection of the equipment are outlined in **Chapter 10**. The equipment, described in this chapter, is generally confined to the major items required in building construction projects. Features of some of the latest construction equipment are listed in **Table 1.8**. The type of plant and equipment employed in 2000 Housing Units Project is shown in **Exhibit 2.4**. The methodology for equipment planning of heavy construction and utility services is similar, but requires specialised know-how of the equipment. Planning of equipment for such specialised projects is beyond the scope of this Chapter as there are limitations of space. Readers are advised to refer to the equipment manufacturers' manuals and standard books on construction equipment for a detailed study. The contents of this chapter can be viewed as guidelines for planning purposes.

❑ 9.1   CLASSIFICATION OF MAJOR EQUIPMENT

Construction equipment classification facilitates; identifying equipment, verifying stock, locating spares, recording repairs, accounting costs, indexing catalogues, logging performance, monitoring effectiveness, estimating outputs, and planning procurements. There are many methods for classifying construction equipment. These include dividing the equipment into special purpose and general purpose machines; classifying equipment according to the alphanumeric code generally conforming to the description of equipment; and categorising equipment into its functional use. In particular, functional classification of major equipment is reflected in **Exhibit 9.1**.

Major equipment that is commonly employed for the execution of a medium sized building construction project, with its task suitability and the output capability, are outlined in subsequent paragraphs.

❑ 9.2   EARTH FACTOR IN EARTHWORK

The most important factor that determines the suitability of equipment for earthwork is the earth itself. The earthwork process is affected by the ground condition. The main ground characteristics, which influence the performance of the equipment, are; the suitability of equipment, the digging effort, volume conversional, and the resulting output.

9.2.1   Equipment Suitability

The type of earthmoving equipment varies with characteristics, such as the nature of the soil and tasks to be performed. Typical job-related equipment used in building projects are given below:

1. Excavating and lifting in soft earth:

Deep pits excavation:	Clamshell and dragline
Shallow pit excavation:	Backhoes
Ground level excavation:	Shovels

Exhibit 9.1

Functional Classification of Construction Equipment

Earthwork Equipment

- Excavation and lifting equipment-backactor (or backhoes), face shovels, draglines, grabs or clamshell and trenchers.
- Earth cutting and moving equipment-bulldozers, scrapers, front-end loaders
- Transportation equipment-tippers, dumps truck, scrapers rail wagons and conveyors.
- Compacting and finishing equipment-tamping foot rollers, smooth wheel rollers, pneumatic rollers, vibratory rollers, plate compactors, impact compactors and graders.

Materials Hoisting Plant

- Mobile cranes-crawler mounted, self-propelled rubber-tyred, truck-mounted.
- Tower cranes-stationary, travelling and climbing types.
- Hoists-mobile, fixed, fork-lifts.

Concreting Plant and Equipment

- Production equipment-batching plants, concrete mixers.
- Transportation equipment-truck mixers, concrete dumpers
- Placing equipment-concrete pumps, concrete buckets, elevators, conveyors, hoists, grouting equipment.
- Precasting special equipment-vibrating and tilting tables, battery moulds, surface finishes equipment, steel pretension equipment, GRC equipment, steam curing equipment, shifting equipment, erection equipment.
- Concrete vibrating, repairing and curing equipment.
- Equipment Forms for RCC work.
- Soil, materials and concrete testing laboratory equipment.

Support and Utility Services Equipment

- Pumping equipment.
- Sewage treatment equipment.
- Pipeline laying equipment.
- Power generation and transmission line erection equipment.
- Compressed air equipment.
- Heating, ventilation and air-conditioning (HVAC) equipment.
- Workshop including wood working equipment.

Special Purpose Heavy Construction Plant

- Aggregate production plant and rock blasting equipment.
- Hot mix plant and paving equipment.
- Marine equipment.
- Large-diameter pipe laying equipment.
- Piles and pile driving equipment.
- Coffer dams and caissons equipment.
- Bridge construction equipment.
- Railway construction equipment.

Shallow trenching: Trenchers, excavators (backhoes)
Wet soil excavation: Excavators (dragline or grab)

2. Cutting over areas:
    - Short-hauls: Dozers
    - Long-hauls: Scrappers

3. Loading and transporting excavated soil:
    - Loading soil: Loaders, shovels, excavators
    - Transporting soil: Tippers, dumpers, scrapers rail wagons, and conveyors

9.2.2   Digging Effort

The digging effort of equipment depends upon the nature of the soil. For example, it is easy to dig in common earth than in stiff clayey soil. The typical soil factor, which determines the comparative required equipment effort in various types of soils, can be taken as under:

Nature of soil	Digging effort	Soil factor
Loam, sand, gravel	Easy digging	1.0
Common earth	Medium digging	0.85
Stiff clay, soft rock	Hard digging	0.67

9.2.3   Volume Conversion

The volume measure varies with the state of the soil. Three states of soil encountered in earth-moving operations are: in-place natural soil, loose excavated bulk soil, and compacted soil. The volume of soil in its in-place natural state is referred to as the bank volume. Soil in its in-place natural states wells when heaped in a loose state after excavation, and shrinks when mechanically compacted. The typical relationship for volume conversion of soil into its three states prior to laboratory testing can be taken as shown in **Table 9.1**.

Table 9.1

Volume Conversion of Soil into Three States

Nature of Soil	Bank Volume	Loose Volume	Compacted Volume
Common earth	1.00	1.25	0.90
Sand	1.00	1.12	0.95
Clay	1.00	1.27	0.90
Rock (blasted)	1.00	1.50	1.30

Example: 100 m³ of unexcavated common earth (bank volume) is required to be hauled.

- What will its volume be when it has been excavated and is ready for hauling?

- What will its volume be if it is compacted?

Solution:

Nature of Earth	Unexcavated (BCM)	Loose Soil (LCM)	Compacted Volume (CCM)
Common earth	100	100 × 1.25 = 125	100 × 0.90 = 90
Sand	100	100 × 1.12 = 112	100 × 0.95 = 95
Clay	100	100 × 1.27 = 127	100 × 0.90 = 90
Rock (blasted)	100	100 × 1.50 = 150	100 × 1.30 = 130

Where, BCM = Bank Cubic Meter; LCM = Loose Cubic Meter; CCM = Compacted Cubic Meter. For a given weight of soil, the swell factor and shrinkage factor are defined as under:

$$\text{Swell factor} = \text{Loose volume/Bank volume}$$
$$\text{Shrinkage factor} = \text{Compacted volume/Bank volume}$$

(a) Loose volume = 100 m^3 common earth x swell factor = 125 m^3
(b) Compacted volume = 100 x 0.95 = 90 m^3

9.2.4 Earthmoving Equipment Output

The equipment capability to perform an assigned earthwork task can best be determined from either on-site actual trials or can be accessed from its past performance records of operation under similar site conditions. The equipment's hourly output is determined by multiplying moved quantity of the earth (load) per cycle by the number of cycles per hour.

$$\text{Equipment actual production/hr} = \text{Actual load/Cycle} \times \text{Cycles/hr}$$

For example, a recently purchased front-end loader operated by a skilled operator with bucket capacity of 1.5 m^3 on a given job involving easy loading, moves a load of 1.5 m^3 of loose soil in one cycle consisting of loading-lifting-traveling-unloading-return trip-and ready for loading. If each cycle time is 1.2 minutes, then

Hourly production per working hour = Actual load per cycle × Cycles/hr
under ideal condition   = 1.5 m^3 × 1.0 × 60 min/1.2 min
      = 75 m^3/hr

Equipment output/hour for planning purposes can be calculated from the haul volume per cycle and the number of cycles using the following formula:

Planned output/hr = Ideal output/hr × Correction factor × Performance efficiency factor

$$P = Q \times q \times N \times E \times C = Q \times q \frac{60}{Cm} \times E \times C$$

Where,

P = Production per hour (m³/hr; yd³/hr) under prevailing situation.

Q = Ideal Bucket/Blade capacity (m³; yd³) per cycle, in loose excavated soil under ideal conditions.

q = Soil volume conversion factor.

Q × q = Ideal production per cycle for given soil condition.

N = Number of cycles per hour = 60/Cm

Cm = Cycle time (in minutes). It mainly depends upon distance, loading, unloading, gear change etc.

C = Correction factor for job conditions

E = Job performance efficiency factor related to equipment condition and operator's skill

Generally, Job Performance Efficiency Factor is assessed in terms of machine operating time per hour or assessed operating condition of the machine. Broadly, it can be expressed as in **Table 9.2**. The method of performance estimation factor is also given in **Section 10.1.3**. Earthmoving equipment output depends upon features; size and salient job suitability. Output capabilities of commonly used earthmoving equipment are outlined in subsequent paragraphs under appropriate heads.

Table 9.2

Estimation of Performance Efficiency Factor

Assessed Equipment Effective Working Minutes/H our	Performance Efficiency Factor
60 minutes/hour	1.00
55 minutes/hour	0.92
50 minutes/hour	0.85
45 minutes/hour	0.75
40 minutes/hour	0.67

❑ 9.3 EARTH EXCAVATING EQUIPMENT

Primary earth excavating equipment is the tractor-mounted machines. Various types of earth excavating equipment with indicative ideal output are listed in **Exhibit 9.2**.

The excavating equipment bucket attachments are divided into four categories; viz. face shovels, backhoes, draglines and grab, or clamshell. Further, excavators can be rope-operated or hydraulically operated. The type and size of the equipment, depends on, nature of the task, type of soil, digging depth, and desired level of production. The approximate output of these machines, for planning purposes, is given in Appendix I. The excavators should have a reasonably levelled ground to operate. The size of the machine is determined by the capacity of the bucket.

Exhibit 9.2

(Ideal Output with correction and performance factors are also reflected in Appendix 9.1)

Earth Excavating and Lifting Equipment Approximate
Ideal Output Per hour (Loose, easy dig)

Types of Equipment	Features		Bucket Struck Capacity					
	Bucket Size	YD³	0.50	0.75	1.00	1.50	2.00	3.00
		M³	0.38	0.57	0.76	1.14	1.53	2.30
	Engine HP		50	75	100	130	160	200
1. Face Shovel								
Power shovel	Maximum Cutting Height	M	7.0	7.0	7.0	7.5	8.5	10.0
	Ideal Output/Hour (Loose, easy dig)	LM³	60	90	120	180	220	300
2. Backhoe or Excavator								
Backhoe	Maximum Digging Depth	M	5.0	6.5	7.5	8.0	9.0	9.0
	Ideal Output! Hour (Loose, easy dig)	LM³	48	72	96	144	176	240
Excavator								
3. Dragline	Maximum Boom Length	M	21	21	21–27	21–27	27–30	30–33
	Ideal Output/Hour (Loose, easy dig)	LM³	45	67	78	135	165	225
4. Clamshell	Maximum Boom Length	M	21	21–27	21–27	21–27	27–30	30–33
	Ideal Output! Hour (Loose, easy dig)	LM³	24	36	48	72	89	120
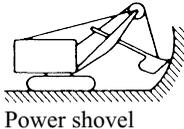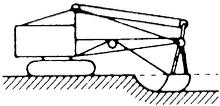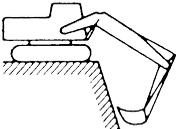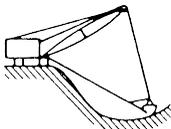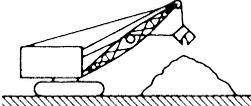
Note: 1. Planning output norms = Ideal Output × Correction Factor × Performance Factor
2. For correction factor and performance factor, refer to **Appendix 9.1**

9.3.1 Face Shovel

It operates from a flat surface, producing upward digging action, excavating and filling the bucket as it climbs. After the bucket is filled, its upper part swings to the dumping position, where the bucket is emptied in a waiting truck or into a stockpile. Thereafter, it returns to its original position and starts the next cycle of excavation. It is capable of working with all types of dry soils. The struck-bucket capacity of the commonly used face shovel bucket varies from ½ yd³ (0.38 m³) to 4½ yd³ (3.25 m³), and depending upon the size of the machine and bucket, its cutting height varies from 6 m to 10.5 m.

9.3.2 Backhoe

It is primarily used for excavating materials below its track level, i.e. excavation of small and large pits, basements, and large trenches. Backhoes are generally track-mounted but small capacity equipment, which have wheel-mounting to add to their mobility. The commonly used backhoes are fitted with buckets that have struck capacity varying from ½ yd³ (0.38 m) to 4¼ yd³ (3.25 m³) and their corresponding digging depth capability from 5 m to a maximum of 9.5 m. Some backhoes also have face shovel mechanism attached with it.

9.3.3 Dragline

It is a rope-operated boom-fitted crane type machine. In this machine, the bucket is thrown into the excavation area and the cable-controlled hook is rotated, so that, the bucket gets filled by scraping the surface to be excavated. It is used for digging below the ground level, specially, in loose soils or marshy and underwater areas with soft beds. The commonly used dragline can operate in a depth of approximately up to 1/3 of its boom length for broad sweeping type excavated work. Its boom length varies from 21 m to 36 m and the struck bucket capacity extends from ½ yd³ (0.38 m³) to 4 yd³ (3.06 m³).

9.3.4 Grab or Clamshell

Like dragline, it is a rope-operated and boom-fitted crane type machine having a grab or clamshell bucket. The grab bucket has interlocking teeth that penetrates in loose soil, whereas, the clamshell bucket has no teeth. These buckets are dropped with their sides open similar to open jaws on the soil to be grabbed, and then, these jaws are closed by rope machines prior to the hauling process. These machines are used primarily for deep confined excavations, such as shafts, wells, and spoil heaps removal. The depth of the excavation can be roughly taken as 1/3 of the boom length. The size range of the grab bucket and its length of boom, are similar to those of the dragline.

9.3.5 Output Planning Data

At the planning stage, the actual on-site trials may not be feasible, and the past performance data may not always be available. It may also not be adequate, as the site conditions vary from place to

place and project to project. In the absence, of these reliable performance methods, the equipment output norms can be derived from the performance data given in the manufacturer's manuals. This off-the-job equipment's hourly ideal output data is reflected in these manuals, in the form of charts, graphs, performance curves, and tables. This 'ideal output' is multiplied by 'soil correction factor' and equipment performance factor for determining the 'output for planning purposes'.

$$\text{Planned output} = \text{Ideal output} \times \text{Correction factor} \times \text{Performance factor}$$
$$\text{Ideal output} = \text{Bucket output/Cycle} \times \text{Cycles/hr (in LCM)}.$$

These are explained below:

a. Bucket output/cycle: A cycle of a bucket starts from the point it strides the excavation place to its return to the next excavation point, after unloading the excavated materials at the specified place in the transporter or on a heap of loose excavated materials. The maximum loose material in cubic meters (LCM) carried in its bucket per cycle is equal to its bucket struck capacity.

b. Cycles/hour: The cycle time is the time taken by the cycle of bucket movements, which includes load, swing, unload, and return to start the cycle again.

$$\text{Maximum number of cycles/hour} = 60 \text{ minutes/cycle time in minutes}$$

The output for the excavating equipment of different types and bucket sizes, is shown in **Exhibit 9.2** and **Appendix I**.

9.3.6   Correction Factors

1. Equipment performance comparison factors relates to the type of equipment employed.

Equipment	Factor Multiplier
Face Shovel	1.0
Backhoe	0.80
Dragline	0.75
Grab	0.40

2. Soil digging factor: It depends upon the digging effort:

Digging effort	Factor multiplier
Easy digging	1.0
Medium digging	0.85
Hard digging	0.67

3. Swing factor: The output varies with the swing angle of the bucket carrying arm, in the horizontal plan, enclosed by the arc, connecting starting point of loaded bucket swing and bucket unloading point on heap or transporter.

	Typical swing factor
Angle of swing:	45° 60° 75° 90° 120° 150° 180°
Factor value:	1.20 1.16 1.05 1.0 0.88 0.79 0.71

4. Load casting factor: Output varies with the method of casting of load.

	Factor multiplier	
Method of casting	**Open area**	**Restricted area**
Side casting	1.0	0.8
Loading in vehicle	0.8	0.6

5. Task efficiency factor: Each equipment is designed for a primary task. There are occasions when equipment is employed on secondary tasks. For example, a backhoe excavating trenches using a bucket of width equal to the width of the trenches. It will yield more output than, if the same bucket is used for excavating trenches of more than the bucket's width. The efficiency of the equipment, when employed on the primary task, is taken as 100% and it can be suitably adjusted using the following guidelines for typical secondary tasks, given in **Exhibit 9.3**.

Exhibit 9.3

Excavator Output Adjustment Factors for Secondary Tasks

Equipment	Nature of Secondary Tasks		Task Efficiency
Shovel	Movement from excavating place to unloading place:		
	a.	Within vicinity	1.0
	b.	Little movement	0.6 to 0.9
	c.	Appreciable; movement or delays	0.4 to 0.6
Backhoe	Trenching		
	a.	Equal to bucket width	1.0
	b.	More than bucket width	0.7 to 0.9
Dragline			
	a.	Bulk excavation	1.0
	b.	Wide open ditches	0.7 to 0.9
	c.	Confined, restricted places	0.5 to 0.7
Clamshell	a.	Dry soil pits	0.9
	b.	Wet soil pits	0.5 to 0.9

9.3.7   Procedure for Determining Planning Output

Planning data.   The output of excavating equipment, for planning purposes, can be easily determined from the equipment output planning table, shown in Appendix 9.1. The procedure involved, is explained with the following example.

Example: Estimate the hourly production in bulk volume (LCM) of a backhoe with bucket capacity of 0.96 M^3 that is employed on excavation of a foundation, which is four meters deep in hard digging soil. The excavated earth is to be loaded in waiting dump trucks, placed at a swing angle of 75°. The expected performance efficiency is 83%.

a. Ideal output of loose soil in cubic meter (LCM) for an equivalent face shovel of bucket capacity of 0.96 m^3 = 150 LCM (approx., refer Appendix I)

b. Backhoe Ideal Output using equipment conversion factor of 0.8 operating at optimum depth = 150 × 0.80 = 120 LCM

c. Correction factors considered are:
   - Soil factor for hard digging = 0.67
   - Load factor for loading into vehicle = 0.80
   - Swing factor for 75 degrees = 1.05
   - Therefore, correction factor = 0.67 × 0.80 × 1.05 = 0.56

d. Performance efficiency = 0.83 (assumed)

$$\text{Hence expected output/h} = \text{Ideal output} \times \text{Correction factor}$$
$$\times \text{ Performance efficiency}$$
$$= B \times C \times D$$
$$= 120 \times 0.56 \times 0.83; \text{Say} = 56 \text{ LCM/h}$$

❑ 9.4   EARTH CUTTING AND HAULING EQUIPMENT

These machines are used to cut and shift earth from one place to another. These machines include bulldozers, scrapers, front-end loaders, and other hauling equipment. Typical equipment for cutting and hauling is sketched in **Exhibit 9.4**.

9.4.1   Bulldozers

The bulldozer is a versatile machine that can be used for moving earth over distances of up to 100 m, clearing and grubbing sites, stripping top unwanted soil, excavating to a shallow depth of up to 200 mm at a time, pushing scrapers, spreading soil for leveling areas, ripping bare soft rock, and maintaining roads. Bulldozers normally are track-mounted; however, there are four-wheeled dozers with large-powered engine. The wheel dozers exert higher bearing pressure as compared to track-dozers.

Exhibit 9.4

Earth Cutting and Hauling Equipment

1. Bull dozers
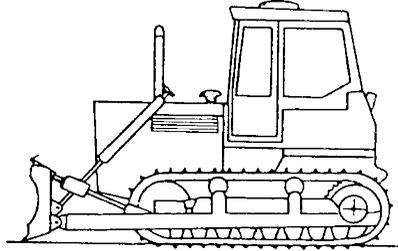
Tracked dozer

2. Front-End Loaders
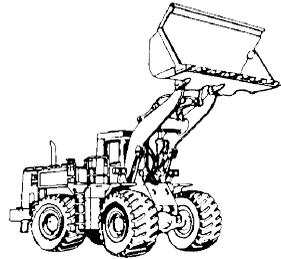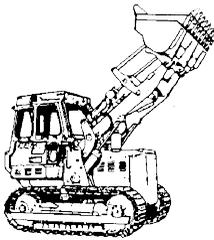
3. Towed Scrapers
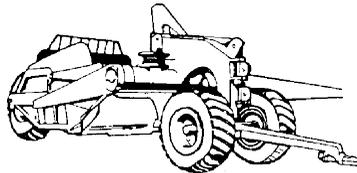
Towed

4. Motorised Scrapers
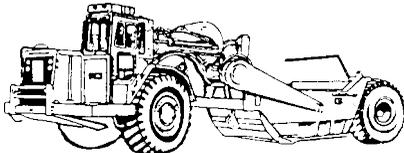
Single engine conventional
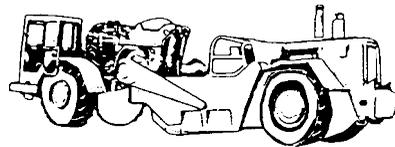
Twin engine conventional
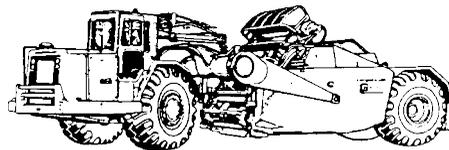
Elevating

Dozers excavate and push earth, with the help of a stiff welded steel blade that is fitted in front and controlled by two hydraulic cylinders. Commonly used blades are of three types, straight S-blade, U-blade, and angle A-blade. The straight S-blade is used for forward pushing of earth. U-blades have large capacity and are therefore; used for pushing loose materials. Angle A-blades are used for pushing soil to one side rather than hauling it in forward direction, for example, in case of hill road formation cutting. A dozer can also be fitted with a backhoe attachment for ripping hard soil and rock, winch for uprooting trees, skidding boulders, and heavy materials.

Ideal output for dozing soft soil depends on the engine power, straight-blade capacity, and dozing distance. The ideal output of bulldozers is shown in Appendix I. This ideal output, measured in the bulk volume (loose soil), assumes forward dozing speed of 3 km/h, return speed of 6 km/h, maneuvering time of 0.15 minutes, easy going on generally level ground, and dozing of (bank) materials using a straight S-blade. This ideal production is corrected to conform to varying conditions as under:

Dozer output planning data = Dozer ideal output × Correction factor × Performance factor

Where, correction factor leads to the following effect:

1. Blade factor-multiply: The ideal output by the blade factor value.

Type of blade	Blade factor
S blade	1.0
A blade	0.75
U blade	1.25 (used only for loose soil)

2. Transmission system: Take 80% of the ideal output, if it is based on the power shift system.
3. Grade factor: The manufacturer's manual provides the data for a change of output with varying slope, but for planning purposes it can be taken as under:

Nature of slope	Effect on output (%)
Downhill working	Increase 2.5 × grade (%)
Uphill working	Decrease 2 × grade (%)

4. Soil factor: The ideal output is based on easy-dig and loose soil. This ideal output should be multiplied by the following soil factors where the nature of soil differs:

Digging Effort	Nature of soil	Soil factor
Easy dig	Loam, sand, gravel	1.00
Medium dig	Common earth in natural state	0.85
Hard dig	Hard stiff clay, soft rock	0.67

5. Swell factor: The ideal output is stated in terms of bulk (or loose) volume excavated. This output can be converted into in-place (or bank) volume by dividing the bulk materials with the swell factor.

$$\text{In-place (or bank) volume (BCM)} = \text{Bulk or loose volume/Swell factor}$$

Example: Determine the output of a bulldozer having 215 HP engine, fitted with A-type blade rated capacity 4.40 m^3. The dozer is employed for excavating a hard clayey area with average haulage of 50 meters, on a ground with down slope of 10%. It has direct drive transmission, and its expected performance is 50 minutes per hour.

Solution: Output/h = Ideal output/h correction factor performance factor.
a. Ideal output/h for 50 meter haulage of 215 HP dozer with 'S' blade of capacity 4.40 m^3 (refer **Appendix 9.1**) = 160 LCM (approximate)
b. Correction factors applicable are:
   - Soil factor for hard digging = 0.67
   - Blade factor for A blade
   - Grade factor for 10% down grade (assistance) = $1 + 2.5 \times 10\% = 1.25$
   - Transmission factor for direct drive = 0.8
   - Swell factor of clayey soil = 1.3
   - Therefore correction factor = $0.67 \times 0.65 \times 1.25 \times 0.8 \times 1/13$

c. Performance factor for 50 min/hour working = 0.83
d. Therefore expected output in BCM = A × B × C = $160 \times 0.42 \times 0.83 = 55.8$ BCM

9.4.2 Scraper

Scraper is the equipment that is commonly used for scraping, loading, hauling and discharging. It also includes spreading large quantities of earth over long distances for around 3 km. It can scrape soils in layers, 15 cm to 30 cm in depth. Basically, a scraper has a soil container or bowl mounted on two wheels. It digs into the earth after lowering of the forward portion of the container, and it collects the earth as the scraper moves forward. Unloading and spreading takes place in controlled layers within the discharge area with the aid of a tractor plate, while the unit keeps on moving. Scrapers come in many sizes varying from 8 m^3 to 50 m^3. There are two main categories of scrapers i.e. towed scrapers and motorized scrapers. They are shown in **Exhibit 9.4**.

1. Towed scrapers. These are pulled by a tractor or a bulldozer that is capable of 300 HP or more. Although the loading cycle may take hardly two to three minutes, its travelling speed is slow. Its main advantage over the motorized scraper is that it can operate in small areas and can scrape in heavy soil areas. Towed scrapers are best suited for medium distances up to 400 m. Towed scrapers capacity ranges from 8 m^3 to 30 m^3.
2. Motorized scrapers. Several types of motorized scrapers with heaped capacity, ranging from 15 m^3 to 50 m^3 are available to suit varying job requirements. These include single engine scraper, double engine scraper and elevating scraper.

a. Single engine scraper requires a pusher bulldozer to provide the necessary tractive force. Generally, one medium-sized crawler tractor is sufficient for serving four to five scrapers.

$$\text{Scrapers per pusher } = \frac{\text{Cycle time of each scraper}}{\text{Cycle time of pusher}}$$

Example: Cycle time of a scraper is 6 minutes and a pusher to fill a scraper is 1.5 minutes. Calculate the number of scrapers, which a pusher can serve. Determine the number of pushers to serve 10 scrapers.

Solution: Number of pushers for 10 scrapes = 60 /1.5 = 4

$$\text{Number of pushers for 10 scrapers } = \frac{\text{No. of scrapers}}{\text{No. of served by one pusher}} = \frac{10}{4} = 3$$

b. Double-engine scrapers are fitted with two engines; one in the front and the other in the rear-axle. For scrapers having capacity of 35 m³ and above, two engines are preferred instead of one large engine. Although, the engine in the rear provides a four-wheel drive, double-engine scrapers require a pusher especially, in hard soil excavations. In the push-pull method, two double-engine scrapers are used to mutually load each other in turn, without the aid of a pusher.

c. Elevating scrapers are fitted with an elevating mechanism for self-loading. Due to their heavy weight, they are at a disadvantage over long hauls.

Scraper output planning data. The ideal indicative outputs of towed scraper and motorized scraper are reflected in Appendix I. This ideal output is for good haulage by road, and this has to be modified by taking into consideration various corrections and efficiency factors discussed above.

$$\text{Output/h in Lm}^3 = \text{Ideal output} \times \text{Correction factor} \times \text{Performance factor}$$

Example: A new motorized scraper, working under average conditions, is deployed in spreading of excavated materials along a road alignment 1.5 km long using the following data:

$$\text{Scraper capacity} = \text{16/23.7 (struck/heap in loose soil m}^3)$$
$$\text{Gross vehicle weight (empty)} = 36 \text{ tons}$$
$$\text{Maximum pay load} = 34020 \text{ kg}$$
$$\text{Material density} = 1500 \text{ kg/m}$$
$$\text{Job efficiency} = 50 \text{ min/h}$$
$$\text{Rated power of engine} = 450 \text{ HP}$$
$$\text{Correction factor} = 0.91 \text{ (estimated from equipment manual)}$$

Evaluate the output per hour after making adjustments for various factors affecting production.

Solution:

1. Production per hour in Lm^3 = Load per cycle (m^3) × Operation efficiency,
   Where Cm = Cycle time in minutes
2. Load per cycle (Lm^3) = Weight of heaped capacity
   $$= 23.7 \text{ m}^3 \times 1500 \text{ kg/m}^3$$
   $$= 35.550 \text{ kg.}$$

   But this weight exceeds pay load of 34 020 kg.

   Therefore maximum load carriage capacity = 34 020 kg
   $$= 22.68 \text{ Lm}^3 \text{ and not } 23.7 \text{ Lm}^3$$

3. Approximate output from Appendix I works out as under:
   Ideal production per hour for 16m^3 (struck capacity scraper) with
   23.7 Lm^3 heaped capacity = 150 m^3 (approximate)
   Correction factor = 0.91
   Performance factor = 0.84
   Maximum load carrying capacity = 22.68
   Scraper heaped capacity = 23.7
   Load carriage capacity factor = 22.68/23.7 = 0.96
   Ideal output × correction factor × performance factor × 0.96 = 150 × 0.91 × 0.84 × 0.96
   $$= 110 \text{ LCM/hr}$$

Note: The Gross Vehicle Weight (GVW), the effective grade (%), the maximum travel speed, and the rim pull (or the drawbar pull), can be determined from the equipment performance charts provided by the manufacturer. This information aids in determining the cycle time, output data, and usable rim pull (i.e. adjusted rim pull) that are necessary to overcome traction of the haulage road.

9.4.3   Loader Shovel

Loader shovel machine, also called as the front-end loader, can be used as earth loader, earth transporter over short distances, and earth excavator in loose soil. It can operate like a face shovel and bulldozer. It is available with wheel mounting and track mounting.

The loader shovel can also be fitted with a backactor attachment. This backactor type loader can be used for light excavation like manholes, drain trenches, small pits, and for loading of materials into tippers. The ideal output data for a loader shovel is given in **Appendix I**.

The quantity of materials that can be hauled by the loader depends on its bucket capacity. Loader bucket capacities are specified by the manufacturer, either in terms of heaped capacity or struck capacity. However, planning can be based on the loose soil struck capacity of the bucket and the heaped capacity (loose soil) can be converted into struck capacity (loose soil) as under:

Bucket struck capacity = Bucket heaped capacity × Fill-factor where fill-factor can be taken as:

Nature of soil	Bucket fill-factor
Common earth	0.95
Sand and gravel	0.95
Hard clay	0.80
Blasted rock	0.70

9.4.4 Hauling Equipment

The type of earth hauling equipment primarily depends on the haulage distance. A rough guideline for selecting the equipment that is based on haulage distance is given in **Table 9.3**.

Table 9.3

Guidelines for Selecting Equipment Based on Haulage Distance (in meters)

	Type of Equipment	**Range of Haulage Distance (m)**
1.	Front-end loader track	Up to 80
2.	Front-end loader (wheeled)	Up to 200
3.	Bulldozers	Up to 80
4.	Towed scrapers	100–300
5.	Elevating self-loading scrapers	100–1000
6.	Single engine scrapers (dozer pusher arrangement)	500–1500
7.	Double engine motorised scrapers (push pull arrangement)	2000 and above
8.	Tippers and dump trucks	800 and above

Mostly, the excavated earth is hauled in heavy duty rubber-tyred tippers, lorries, and rear-opening dump trucks. Over long distances, these vehicles vary in capacity from 5 m³ to 30 m³ dumpers. Tipping lorries are employed for transporting materials over levelled grounds, whereas, dumpers are used for moving large quantities of materials across rough areas. Generally, front-end loaders and excavators are used to load tippers and dumpers. The number of haulage vehicles required can be calculated as under:

Haulage vehilce required = 1+ (Cycle time per trip of vehicle)/(Load filling time of vehicle)

Example: Construction of a military helipad at an altitude of 2400 m involves 80000 m³ (loose) of excavation area in soft soil. This task needs to be completed in 200 working hours. The company entrusted two dozers each with an output of 220 m³/h under job conditions for task execution. It

also holds wheel loaders and 22 m³ dump trucks. One loader can load in trucks of about 120 m³ of excavated soil per hour. The dump truck cycle time for disposal of excavated materials is 35 minutes. This includes 7 minutes of loading time by a loader team that consists of 2 loaders. Estimate the output of front-end loader for loading excavated soil heap into dump trucks and determine approximately the number of dozers, loaders, and dumpers required to complete the task on time.

Solution:

$$\text{(a) Dozers required} = \frac{\text{Excavation quantity}}{\text{Output/h} \times \text{Working hour}} = \frac{80{,}000}{220 \times 200} = 2(\text{say})$$

$$\text{Loaders required} = \frac{\text{Excavation/h by dozers}}{\text{Loader output/h}} = \frac{\text{No. of dozers} \times \text{dozer ouput/h}}{\text{Loader output/h}}$$

$$\text{(b)} \qquad = \frac{2 \times 220}{120}$$

$$= 4 = 2 \text{ loader teams, each team consisting of 2 dozers.}$$

$$\text{(c) Dumpers required} = 1 + \frac{\text{Dumper cycle time}}{\text{Loading time}}$$

For each loading team of 2 front end loaders

$$\text{Dumpers} = 1 + 35/7 = 1 + 5 = 6$$

Total dumpers required for 2 loading teams = 2 × 6 = 12.

❑ 9.5 EARTH COMPACTING AND GRADING EQUIPMENT

The compacting process increases the density of soil by reducing void space ofair. Consolidation, on the other hand, increases soil density by reducing water voids. Consolidation, is a long-term process, which is spread over years, whereas, compaction can be achieved in a few hours. Compaction improves bearing strength, permeability, and compressibility. Compacting equipment combine their static weight with tamping, vibration, impact, and kneading action to produce the desired compacting effort. Requirement of compaction equipment varies with soil characteristics and compacting effort. **Exhibits 9.5** and **9.6** show the types of compacting equipment. The compacting equipment can be broadly classified into tamping foot rollers, pneumatic tyred rollers, vibratory rollers, impactors, plate vibrators, and smooth steel-wheel rollers.

9.5.1 Segmented Pads and Tamping Rollers

A tamping roller consists of one or more hollow steel cylindrical drums with rows of steel studs mounted on it. As the roller is towed with a crawler tractor, these studs are punched into the soil

Exhibit 9.5

Common Earth Compacting Equipment

Type of Rollers

1. Sheep foot rollers

2. Vibratory rollers
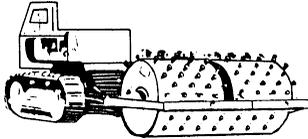
Towed sheeps foot roller
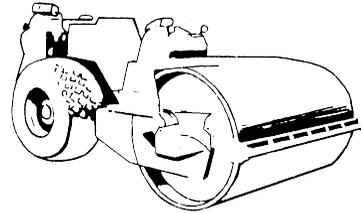
Self-propelled vibrating roller

3. Steel drum rollers
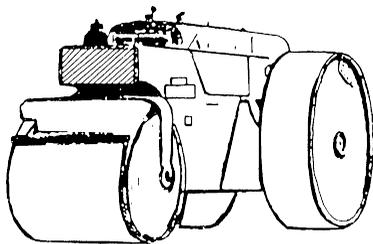
4. Multi-tyred pneumatic rollers

Smooth, steel wheel roller
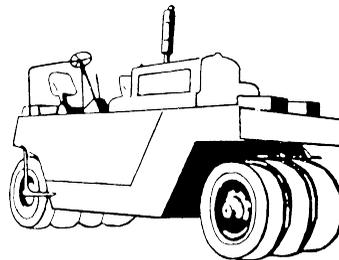
Small, multi-tyred pneumatic roller

and compact it by performing tamping and kneading action. Generally, the compaction takes place to a depth of 150 mm. The cylinder drum can also be filled with water or sand to add extra weight while compacting.

The compaction depends upon the nature of the soil and the roller passes are continued till the feet do not dig into the compacted surface. There are many varieties of tamping the foot rollers. These include sheep's foot rollers for compacting very cohesive soils; tamping foot rollers for compacting soil with low to medium cohesiveness; and grid or mesh segmented rollers for compacting granular soils; especially gravels. In general, the compaction depth achieved in layers with the sheep's foot roller is nearly equal to the depth of the stud. Tamping foot rollers are rated in terms of static load or foot pressure (termed the ground contact pressure) on the soil surface unit area.

Exhibit 9.6

Typical Compacting Equipment: Salient Features

Type	Weight (Tons) Static	Other Ballasted	Rated hose power	Working Speed K.M.P.H. average	Rolling width m³	Other features Maximum wheel loading tons	Soil loose lift maximum cm
Pneumatic Rollers							
(a) Light 15 inch dia wheels 9 to 13 wheels	3 to 9	10 to 15	40-110	5-12	170-250	1.25-2.0	70 cm
(b) Medium 20 inch dia wheels 7 to 11 wheels	6 to 10	21-30	80-130	6-15	185-240	2.25-3.00	70 cm
(c) Heavy 24 inch dia wheels, 7 wheels	10 to 12	30-35	100-130	6-16	200-240	4.50-5.00	70 cm
Segmented and Tamping Foot					**Production**	**Capacity LPH**	
(a) Light self-propelled	15 to 18	-	130-250	5-20	21-27	700-900	Up to depth of foot
(b) Medium self-propelled	20 to 28	-	250-350	5-20	24-30	900-1200	Up to depth of foot
(c) Heavy self-propelled	30 to 50	-	400-600	5-20	36-42	1600-2500	-
(d) Towed	-	-	-	3-8	18-30	300-600	Up to depth of foot

Vibratory

			Dynamic Force			**Frequency Vibration/min**	
(a)	Roller self-propelled (with) pneumatic rear (wheels	to 25 6	-	65-150	150-250	1400-1800	cm 100
(b)	Towed	3-12.5	-	25-75	150-210	1300-2200	cm 100
(c)	-Tandem self propelled	1.5-2.5	-	25-35	75-90	2500-3000	cm 100
(d)	-Plate self propelled	4-6.5	-	50-75	375-400	2100-420	cm 100

Smooth Steel Wheel

Blasted

(a)	2-Axle Tandem	-	5-14	40-150	100-135	-	cm 30
(b)	3-Axle Tandem	-	16-20	75-120	100-135	-	cm 30
(c)	3-wheel	-	6-14	75-120	175-210	-	-

Small Scale Work

						Frequency Vibration/min	
(a)	Vibratory roller	0.2-6.0	-	5-40	3-10	Up to 80	cm 100
(b)	Vibratory plate compactors	0.1-1.0	-	2-10	1.0-1.5	Up to 80	cm 70
(c)	Stampers	Approx 0.1	-	2-4	-	Up to 80	cm 50

9.5.2   Smooth Wheeled Rollers

These rollers have one or more smooth steel wheels and are generally self-propelled. The self-propelled tandem and 3-wheeled rollers are used for finishing compaction of layers, up to 150 mm of sand, gravel and water bound macadam are used in base courses. Smooth wheeled rollers are employed for compacting bituminous materials, especially the top layers in road surfacing operation. Smooth wheeled rollers are classified by type, weight, or both. Various types of rollers include 3-wheel two axles, 2-wheel tandem and 3-wheel tandem. The weight of the rollers can also be increased by ballasting with water, sand, or pig iron. Rollers are designated in terms of static and ballasted weight, i.e. 15/20 tons, means that the static weight of the roller is 15 tons and the maximum weight when ballasted is 20 tons. In order to indicate the exerted pressure, these rollers are also designated, by specifying the minimum weight per linear width of roller, i.e. 60 kg/cm width.

9.5.3   Pneumatic Rollers

Pneumatic rollers are available in light, medium, and heavy weights. They compact soil with the kneading action. The weight of the equipment can be nearly doubled with ballasting using water, sand, or pig iron, and the ground pressure can be maintained as desired by controlling the weight of the ballast, the number of the wheels, the width of the tyres, and the tyre pressure. The pneumatic tyred rollers are rate d in terms of tyre pressure (ground contact pressure) per unit area. It may be noted that the load on the tyres determines the depth on which compaction is possible, where both, the tyre pressure and the tyre load are important for achieving compaction near the surface (See **Table 9.4**).

Table 9.4

Load Requirement for Compaction at Different Depths

Passes	Job Characteristics	Maximum Depth of Layer (in mm)	Load Desired (in tons)
4 to 8	Compaction of loamy sand	300 mm	1.5 to 1.7
		500 mm	2.0 to 2.5
		700 mm	4.0 to 4.5
4 to 6	Compacting bituminous material	80 mm	1.5
		130 mm	2.5
		200 mm	4.0

9.5.4   Vibratory Rollers and Compactors

Vibration improves compaction and save time as compared with the static weight method of compaction. Vibrations set the rim roller in oscillation, which in turn transmit vibrations to the soil.

Vibrations are induced by installing a rotating eccentric weight inside the roller drum. Vibratory rollers combine the static weight with dynamic forces. Maximum compacting effort is produced when the resonance frequency of the roller and soil coincide.

Generally, the rating for the vibratory compactor is stated as total applied force' expressed in tons and it is the numerical sum of the dynamic forces plus static weight. The vibrating frequency is specified as cycles/minute, Vibration frequencies range from 1400 to 3000 cycles/minute. Further, a slow displacement speed of 2.5–4 km/h produces a better effect than speedier movement. Vibratory compactors are of various types and size. These include smooth drum vibratory rollers and tamping foot vibratory rollers. Moreover, these are widely used for compacting non-cohesive soils.

9.5.5 Manually Operated Plate and Impact Compactors

These are operated manually and are used for compaction of small stretches, like base and trenches in a building foundation work. In plate compactors, vibrations are provided by installing two eccentric weights that rotates in opposite directions around the centre of gravity of the plate. Plate compactors are more effective on granular materials, whereas, impact compactors are preferred for cohesive materials. The compacting effort in the impact or tamping compactor is delivered by raising a heavy weight and then dropping it on the surface of the soil. These compactors are mostly hand operated. However, track-mounted cranes can also be improvised leading to a free fall hammer effect on the soil surface.

9.5.6 Production Output of Roller Compactors

The nature of soil dictates the type of compacting equipment required and the dry density, which can be achieved. After the compacting equipment is selected, its average output can be calculated as under:

$$\text{Compaction in m}^3\text{/hr} = \frac{\text{WSTEC}}{p}$$

Where,

W = Width compacted per pass in meters (M)
S = Compactor speed in M/h
T = Thickness of compacted layer
E = Job efficiency factor
C = Compacting factor
P = Number of passes required (varies from 4 to 6)

In the absence of actual data, the compacting factor can be assumed as shown in **Table 9.5**.

Water requirement in litres per hour = weight of loose soil to be compacted per hour in kg
$\times$ (optimum moisture content-natural moisture content)

Table 9.5

Compacting Factor for Different Types of Soil

	Compacted Volume	Loose Volume	In-place Volume	In-place Dry Density
Common earth	1.0	1.41	1.18	1.8
Sand	1.0	1.21	1.18	1.7
Clay	1.0	1.48	1.11	1.9
Gravel	1.0	1.17	1.11	2.0
Crushed stone	1.0	1.30	0.75	2.2

Notes:
1.   The above data can be used for initial planning purposes. However, field trials are necessary to determine the optimum moisture content, loose layer (lift) thickness, roller weight, and the number of passes that yield a certain compacted thickness of the layer having a specified field dry density.
2.   It is necessary to assess the requirement of water for compaction so as to develop a water distribution system including requirement of water tenders.

For example, water required per hour for compacting loose soil being spread by a shovel and dozer at the rate of 230 m³/h for a soil having density of 1.5 gm/m³ and 8% moisture content needing 12% optimum moisture content for compaction

$$= 230 \times 10^6 \times 1.5 \times \frac{12-8}{100} \times \frac{1}{1000} = 13800 \text{ litres water/hour}$$

9.5.7   Graders

These are used to grade earthen road formations and embankments to their finished shape, within specified limits by trimming the surface. The graders can also be used for forming ditches, mixing and spreading soils, backfilling, and scarifying ground.

The motor grader is the equipment that is mostly used for grading and finishing, large areas. Motor graders generally have engines up to 300 HP and the latest models, are provided with hydraulically controlled attachments. These attachments include an excavation blade similar to that of bulldozer, scarifier, ripper, and backhoe. The blade of the motor grader has replaceable cutting edges. These blades come in flat, curved, and serrated styles. Motor graders are fitted with articulated frames for increasing maneuverability. Motor graders are now available with automatic grade controls for achieving the desired grading. Grading distance of 500 metres and above results in optimum output; for shorter distances, task efficiency gets reduced:

Distance in meters	50	100	200	500
Task efficiency	0.4	0.6	0.8	1.0

Graders' optimum output for finishing is measured in M2/hour on an area basis or km/hour on a linear basis:

$$\text{Output in m2/lOur} = \frac{\text{W.S.E.}}{\text{P}}$$

Where,

W = Width graded per pass
S = Average speed in m/h
E = Job efficiency factor
P = Number of passes (generally 4 to 6)

and the grader speed for various operations can be taken as under:

Operation	Speed (km/h)
Rough grading	4–10
Finishing (including grading)	6–15
Mixing	15–30
Spreading	6–15
Self-transporting	10–40

Example: Calculate the time required to grade and finish 30 km of road formation with width equal to thrice the width of the motor grader, using six passes of the motor grader with speed for each of the successive two passes as 6 km/h, 8 km/h and 10 km/h respectively. Assume machine efficiency based on operator's skill, machine characteristics and working conditions as 75%

$$\text{Average} = \frac{2 \times 6 + 2 \times 8 \times 2 \times 10}{6}$$
$$= 8 \text{ km/h}$$

Area to be graded per hour

$$= \frac{\text{Width graded per pass} \times \text{Average speed} \times \text{Machine efficiency}}{\text{Number of passes}}$$

$$= \frac{\text{W} \times 8 \times 1000 \times 0.75}{6}$$

Number of hours required to grade and finish 30 km long and 3 W wide area

$$= \frac{\text{Total area}}{\text{Area/hr}}$$

$$= \frac{30 \times 1000 \times 3W}{[W \times 8 \times 1000 \times 0.75] \div 6} = 90 \text{ hours}$$

❑ 9.6 CONCRETING PLANT AND EQUIPMENT

Concrete is produced by combining basic materials like cement, aggregate, and water. By combining these materials results into a homogeneous and suitably designed plastic mix that solidifies into structural and non-structural building members. The process of concrete production involves, batching, mixing, transportation, placing, consolidating and curing. The major equipment that are used for production, transportation, and pumping of concrete are outlined in the subsequent paragraphs and shown in **Exhibit 9.7**. The designing and erection of the formwork that is needed for shaping concrete, is a subject in it self and is not covered in this chapter.

9.6.1 Concrete Batching and Mixing Equipment

Batching is the process of proportioning cement, aggregates, water, and admixture (where added), by weight (commonly used method) or volume, prior to mixing. The equipment used for batching and mixing can be divided into three categories, viz. mobile concrete mixers; centralised batching and mixing plant; and mobile truck mixers; which are covered under concrete transportation.

9.6.2 Mobile Concrete Mixers

These mixers have a conical or circular rotating drum with baffle fittings inside it. These are mounted on pedestals with facilities for batching of various concreting materials. There are three types of concrete mixers, viz. tilting drum mixers, non-tilting drum mixers, and reverse drum mixers. Tilting drum mixers discharge the concrete by tilting the drum. They are used for producing very small quantities of concrete or mortar mixes.

Non-tilting drums are suitable for requirements of up to 10 m^3/h. These have a hopper-fitted outlet on the top for loading and another chute-fitted outlet on the bottom for discharge. The reverse-drum mixers mix in one direction and discharge in the opposite direction.

The mobile concrete mixers vary in size from 100 litres to 400 litres. The size of the concrete mixers denotes the volume of concrete that can be mixed in a single cycle and usually it is expressed in cubic feet or cubic meters or in the ratio of the concreting materials volume to the wet concrete volume. For example, 21/14 means a concrete mixer having maximum capacity to hold dry concreting materials up to 21 cubic feet and is capable of producing wet concrete of 14 cubic feet. Concrete mixers are available as static units and trailer-mounted towed units.

The hourly output of concrete mixer can be calculated by multiplying production in m^3 per batch or cycle into the number of batches per hour. In the absence of actual data, for planning purposes, the hourly output for concrete mixers of various sizes, can be taken as shown in **Table 9.6**.

Exhibit 9.7

Major Concreting Equipment

- Mixing Equipment
  - Portable Concrete
  - Batching Plants
- Transportation Equipment
  - Transit Mixers
  - Concrete Dumpers
- Delivery Equipment
  - Concrete Pumps
  - Others
    - Hoist
    - Conveyors
    - Concrete Buckets
- Compacting Equipment
  - Needle vibrators
  - Surface vibrators

Concrete Pump

Concrete Pump

Transit Mixer
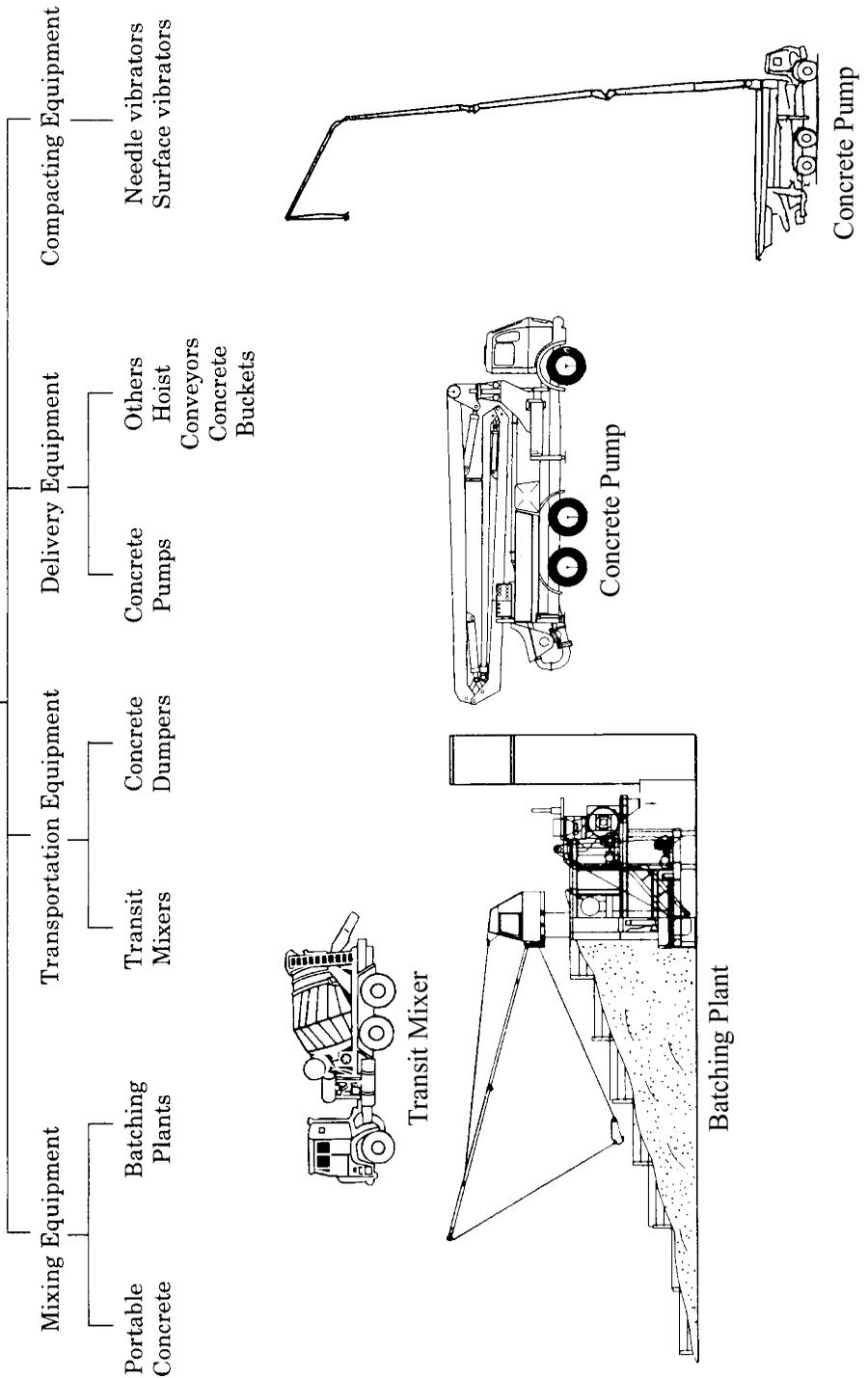
Batching Plant

Table 9.6

Hourly Output for Various Sizes of Concrete Mixers

Mixer size		Batch/hour	(Output (M³/hour
7/3.5	(100 litres)	17	1.7
7/5	(140 litres)	16	2.3
10/7	(200 litres)	15	3.0
14/10	(280 litres)	14	3.9
21/14	(400 litres)	12	4.8
32/21	(600 litres)	10	6.0

9.6.3 Central Batching Plant

A central batching plant includes all types of equipment and materials that are necessary for providing input to the mixers and delivering output to the concrete transporting system. Batching plants can be divided into two categories, viz. medium size or low profile batching plants, and large volume or high profile patching plants. Generally, medium size batching plants have a rated capacity of 25 m³/h to 60 m³/h and produce concrete for building construction projects, whereas, batching plants having higher capacity, such as 120 m³/h, are employed for heavy construction or used in the ready-mix concrete supply business.

Experience dictates that for planning purposes, the average output of the central concrete batching plants be taken as 60%–70% of the hourly rated capacity for each working hour. So, as to cater for various correction factors specially idle-time on account of non-utilisation period and repairs.

9.6.4 Concrete Transportation Equipment

Equipment that is used for transportation of concrete, from mixer to placing site, depends on the distance and the volume of concrete to be placed. Wheelbarrows, with limited capacityof0.04 m³, and, small motorized dumpers, with capacity up to 1.0 m³ are used for transporting and placing small quantities of concrete at site.

Concrete transit mixers are employed for transporting large quantities of concrete over long distances. These mixers have a rotating drum mixer mounted on a truck. These transit mixers transport wet concrete from the mixer to the placing site, and their rotating drums carrying capacity varies from 3 m³ to 9 m³ concrete. Concrete specifications restrict the time from loading to discharge of the concrete mixer as one hour without retarders, provided the drum is kept rotating to agitate the wet mix. For long distances, such as exceeding two hour's travel time, the dry mix can be transported in especially designed truck-mixers and the concrete is manufactured at the placing site, by mixing these materials with water. The number of truck-mixers required for transporting concrete can be worked out by evaluating the cycle-time. Consider, a typical mixer cycle-time data of 6 m³

truck-mixer, is given below:

$$
\begin{aligned}
\text{Loading time for 6 m}^3 \text{ truck-mixer} &= 14 \text{ minutes} \\
\text{Travel time of loaded truck-mixer to site} &= 7.5 \text{ minutes} \\
\text{Average waiting time at site} &= 7.5 \text{ minutes} \\
\text{Discharge time at site using concrete pump} &= 15 \text{ minutes} \\
\text{Travel time for return trip} &= 5 \text{ minutes} \\
\text{Total cycle time} &= 49 \text{ minutes}
\end{aligned}
$$

Therefore truck-mixers required for continuous supply

$$
\begin{aligned}
&= \frac{\text{Cycle time}}{\text{Discharge time}} + 1 \text{ (spare)} \\
&= \frac{49}{15} + 1 \\
&= 5 \text{ Nos.}
\end{aligned}
$$

Notes:

1. Cycle time should be divided by discharge time (as illustrated above) or loading time, whichever is higher.
2. Concrete placing rate at delivery site (m³/h) should be kept marginally less than the loading (or production)-rate due to the following reasons:
a. Concrete placing should proceed continuously as waiting in between can result in improper jointing, especially, if the time interval between the initial deposit of concrete and subsequent deposit exceeds concrete initial-set period.
b. Concrete loading at the batching plant can be suitably controlled as and when the queue of loaded truck-mixers starts building-up at the placing site.

9.6.5   Hauling and Placing Concrete

At the delivery site, the concrete transported by truck-mixers is hauled horizontally and/or vertically for final placing into the forms. A small quantity of concrete can be hauled at the site by using wheelbarrows, chutes, portable belt-conveyors or hoisting units. Haulage of a large quantity of concrete needs a crane-and- bucket arrangement; however, the latest trend is to use concrete pumps.

Concrete buckets come in different sizes that are attached to hooks of suitable cranes for lifting concrete at desired heights. These buckets have a bottom gate, which can be released manually for discharging concrete at the desired location. Concrete buckets can also be tied up with fork-lifts for moving concrete over short horizontal distances. Concrete pumps provide the most acceptable, easy, and quick method of placing concrete. These are commonly used in the industrialised countries. Concrete pumps can be broadly divided into two categories, viz. truck-mounted mobile pumps and trailer-mounted stationery pumps.

Truck-mounted mobile pumps have the ability to deliver concrete up to 120 m^3/h at a height above 40 metres. It creates handling and logistic difficulties. Usually mobile concrete pumps, operate in the range of 35-45 m^3/h or even less. The pumping distance and the price of the pump, depends on the boom length of the pump. For planning purposes, the vertical distance at which a concrete pump can deliver concrete with its boom can be taken as 2/3 of the boom length with remaining boom length being used for placing concrete horizontally. The mobile concrete pumps are frequently moved from place to place. They can also be used in the stationery mode of delivering concrete, horizontally or vertically, up to the designed distances, by fixing and suitably anchoring extension pipes.

The stationery concrete pumps are mounted on trailers and are occasionally moved. These are positioned in the vicinity of the place, where concrete is to be delivered by pumping concrete vertically or horizontally. The pump is connected to the delivery site by a pipeline through which the concrete is pumped. Pumping distance further depends on the capacity of the pump, horizontal as well asvertical pumping distance, and the nature of bends in the pipeline. These details can be found in the manual of the concrete pump. The truck-mounted mobile concrete pumps are preferred to trailer-mounted stationery pumps due to their mobility, flexibility, ease of maintenance, and higher pumping capacity. Gradually the stationery pumps, though cheaper for certain work situations, are being replaced by the truck-mounted mobile concrete pumps.

9.6.6   Consolidating and Finishing

Consolidation aims at removing air voids from the concrete at the time of placing it. Further, consolidation is achieved with the help of concrete vibrators, which come in different sizes depending on the nature of their vibrating application, such as in narrow slits, columns, slabs, mass concreting, etc. Finishing operations make use of screed vibrators, manual/power trowels, and tools necessary for undertaking various types of finishes, such as exposed aggregate, broom, and textured pattern shape finishes.

❑ 9.7   CRANES FOR MATERIAL HANDLING

Cranes are predominantly used for purpose of handling including lifting, lowering, and swing shifting of small to heavy loads. Cranes come in various types, such as crawler-mounted mobile cranes, self-propelled rubber-tyred wheels, telescopic jib cranes, truck-mounted strut-jib cranes and tower cranes. The commonly used cranes are shown in Exhibit 9.8.

9.7.1   Mobile Cranes

In case of project sites, spread widely, mobile cranes provide the best means for lifting and shifting of small to heavy loads. These cranes can move over levelled firm surfaces as well as rough terrains. Mobile cranes are of the following types:

Crawler-mounted cranes.   These cranes spread their dead load over larger area through their long tracks and are useful, while, working in unprepared surfaces. The boom of these cranes comes

in sections, which are joined by pin connections. The straight boom can lift loads over a radius of 30 to 40 metres. In order, to overcome the ground obstruction to the inclined boom, a fly-jib (say, 18 meters in length) is attached to the top of the end boom, as shown in **Exhibit 9.8**. The fly-jib is generally inclined at 30 degrees offset from the main boom acting as its extension. The crawler jib crane can also be converted into a grabbing crane or dragline crane, by fitting with the appropriate attachments.

Self-propelled rubber-tyred wheels cranes.   These cranes have greater mobility over hard surfaces and therefore; in great demand for shifting and transporting light loads over short distances and for off-loading of medium to heavy loads. Self-propelled cranes can be broadly divided into three categories:

1. Strut-jib cranes for shifting small loads at a distance, where ground obstruction restricts the utility of the crane;
2. Cantilever-jib crane provides greater clearance under the jib for heavy and bulky loads; and
3. Telescopic-jib crane provides flexibility in adjusting distances and heights of lifts. It has greater mobility on roads than other self-propelled cranes.

Truck-mounted cranes.   These cranes are used for lifting medium to heavy loads over high and wide places, such as placing pre-cast concrete slab panels in a high rise building or installation of heavy mechanical equipment, such as vessels in production industries. These cranes have a capacity ranging from 10 tons to 100 tons. Cranes of capacity greater than 100 tons are custom-made. Their main advantage is that they can move on roads and take hardly few minutes to prepare themselves for the lifting operation. Truck-mounted cranes are available with telescopic-jib and strut-jib. These cranes have hydraulically operated outriggers, which get stretched out and are made to rest on firm ground, in order to provide a stable base.

9.7.2   Tower Cranes

Tower cranes are extensively used in building projects, especially in high rise construction sites, where work concentration is in a limited area. The tower crane configuration enables the erected crane close to the building, and its height enables its jib to swing for clearingobstructions. These cranes have 360 degree slewing' capability and are electrically powered. Depending on the nature of the primary task, the tower cranes (both horizontal-jib and luffing cranes) can be grouped into following types:

1. *Stationery c*   . These are supported on basis of their foundations. Their mast is bolted to a fixed-position steel base placed on top of the foundations and their ballast counterweight rests on the base. These cranes can go up to 100 metresin height and are mostly, used for high rise buildings. The height of these cranes can be increased further by suitably bracing the mast with the building structure.
2. *Tr   c*   . The steel base of these cranes is mounted on travel-gear and rests on rail-tracks embedded in the foundation. This enables the crane to travel along the track. The load

Exhibit 9.8

Materials Handling Equipment

Materials Handling Equipment
- Mobile Cranes
  - Crawler-Mounted Cranes
  - On-Wheels Cranes
    - Telescopic-Jib
      - Self-Propelled
      - Truck-Mounted
    - Strut-Jib
      - Truck-Mounted
      - Truck-Mounted
- Tower Cranes
  - Stationary
    - Climbing
  - Travelling
    - On-Rails
    - On-Wheels
    - Crawler-Mounted
- Other Machines
  - Gantry Cranes
  - Overhead Cranes
  - Hoists
  - Fork Lifts
  - Belt Conveyors
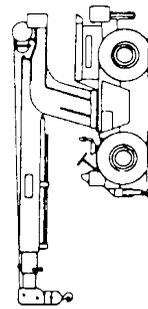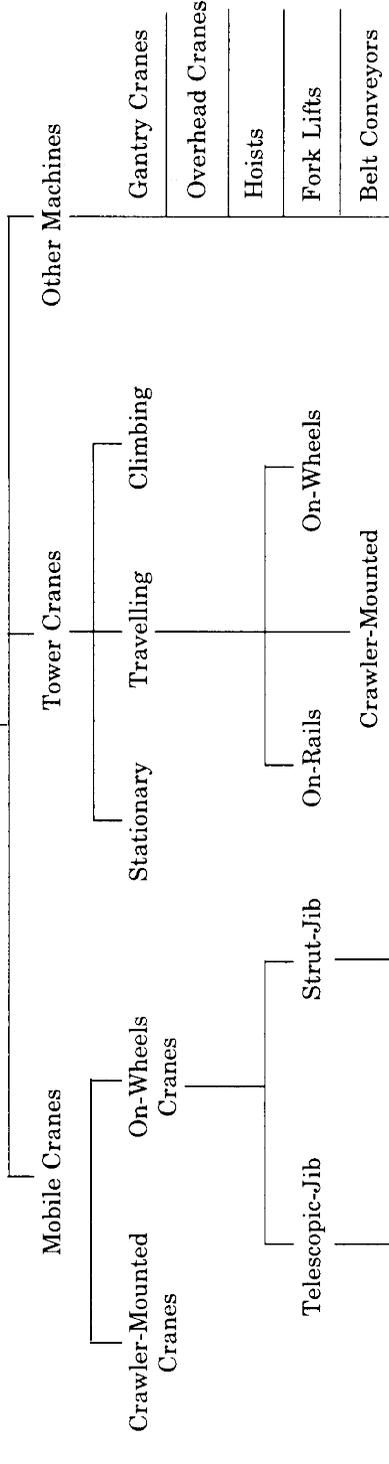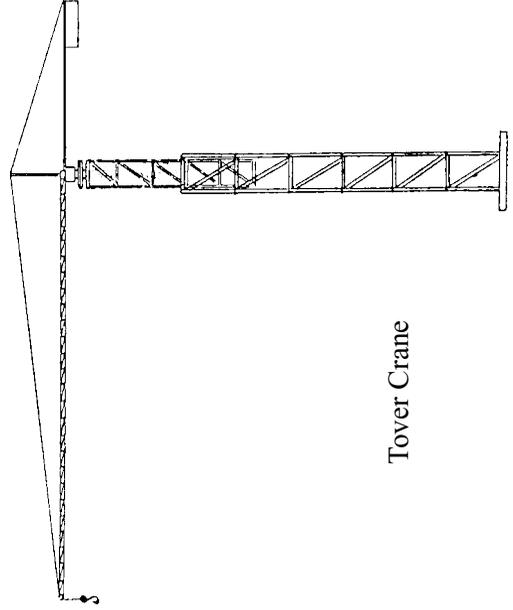
Tower Crane

Mobile Crane

travelling cranes can be used for constructing long buildings, shifting heavy materials like precast elements, and batched concrete from the production site, to the adjoining places or transportation areas.

3. *Climbing cranes*. These cranes are positioned on solid cores, like the lift shaft inside a multi-storey building. Initially, two storeys of the building are constructed by placing the crane outside the core on a selected part of the building foundation. The crane is, then positioned at the core by securing it with special collars, resting it on the walls of the core. Thereafter, the crane erects the building around itself and climbs up, when the mast supported on the collars is raised by winches or hydraulic jacks. Climbing cranes are economical and useful, where the shortage of sufficient external space around the building does not permit the erection of other tower cranes.

It may be noted that the erection of the tower cranes needs careful planning and is generally entrusted to experienced persons or agencies.

9.7.3   Estimating Crane Output

The crane's capacity to handle loads from one location to another is given by:

$$\text{Crane output/hr} = \text{Load/cycle} \times \text{Cycles/hr}$$

Calculation of the output and cycle time depends upon many variables and can best be determined by referring to machinery manuals and site trials. It is important that manufacturers' manuals must be referred to in order to determine the tipping load at a given radius and the safe working load of the crane. Generally, the safe working load varies from 67% to 75% of the theoretical crane tipping load.

For initial planning purposes, the cycle time can be computed as outlined below. However, the data indicated is for illustration purposes only:

Therefore, the above crane, operating with job efficiency of 44 min/h and shifting a 5 ton load in each cycle, shall handle 5 ton load × cycles in one hour (of 44 minutes performance).

S. No.	Activity	Time in minutes (medium-sized crane)
1.	Hooking load at ground level	= 1.0 min
2.	Raising load from ground level to a height of 30 metresat 60 metres/minute	= 0.5
3.	Slewing through 120 degrees at 60 degree/minutes	= 0.5
4.	Travelling on rails for 45 meters at 30 metres per minute (where applicable)	= 1.5
5.	Moving trolley at jib level for unloading and positioning by 15 metres at 15 metres per minute	= 1.0
6.	Unhooking load	= 1.0
7.	Lowering load by 5 metres at 60 to 100 meters/minute, and resting at the proper place	= 1.0

8.	Raising hook by 5 metres (overlapping)	= 0.0
9.	Slewing to original loading position	= 1.0 min
10.	Moving trolley at jib level to loading position	= 0.5
11.	Travelling on rails to original loading position (where applicable)	= 1.5
12.	Lowering hook	= 0.5
Total cycle time after disregarding effect of small overlapping activities		= 11.0

$$= 5 \times \frac{44 \text{min}}{11 \text{min}}$$
$$= 20 \text{ tons/h}$$

It may be noted that the rated crane capacity is equal to the maximum load lifting capacity at the minimum operating radius.

APPENDIX I

Earthmoving Equipment Planning Data for Primary Tasks

❑ I.1   INTRODUCTION

Planning Output Norms = Ideal Output × Performance Factor
× Correction Factor

The output of the earthmoving plant depends upon many variables. These variables include nature of work, depth of cut, earth hauling, job conditions, management conditions, skill of operator, performance worthiness of equipment, and method of disposal of the excavated material. The output of the equipment can be best assessed by an experienced person from the past performance data of the equipment. This data includes number of hours done, output achieved, speed of operation, maintenance and repairs, and the skill of the operator. But such reliable data is rarely available.

In case of new equipment, the performance diagrams are given in equipment manual, which provide a useful method of estimating equipment, but there is no substitute to the knowledge and experience of the manager employing the equipment. In particular, the construction manager and the planning engineer of construction project should be able to assess the approximate output of

equipment, which they expect to employ at the construction site. This appendix provide thumb rule for determining output of the earthmoving equipment.

❑ I.2 TRACKED BULL DOZER IDEAL OUTPUT PER HOUR IN BULK VOLUME IN EASY-TO-DOZE LOOSE SOIL

$$\text{Planning Output Norms} = \text{Ideal Output} \times \text{Performance Factor} \times \text{Correction Factor}$$

Job Conditions. Assume dozing speed as 3 km/h, return speed as 6 km/h, and maneuvering time as 0.15 min.

$$\text{Ideal output in one hour} = \text{Straight blade capacity} \times \text{Cycles in 1 hr, uninterrupted production}$$

HP range	Straight blade capacity		Dosing distance in metres (one way)			
	yd³	M³	Up to 25	50	75	100
250–300	8	6.11	400	220	150	110
180–250	6	4.58	300	160	110	80
120–180	4	3.06	200	110	70	60
100–120	3	2.23	150	80	50	40
75–100	2	1.53	100	50	40	30
50–75	1.5	1.14	70	40	30	20

❑ I.3 FRONT-END LOADERIDEAL OUTPUT PER HOURIN BULK VOLUME EASY-TO HAUL LOOSE SOIL

Job Conditions. Assume digging and dumping time as 0.4 min, speed (loaded) as 4 km/h and return empty as 12 km/h, uninterrupted production.

Bucket Capacity	Output per hour in m³								Bucket Capacity
6.12 m³	410	265	245	155	130	110	95	85	8 Yd³
4.6 m³	310	200	185	115	95	80	70	60	6 Yd³
3.06 m³	205	135	125	75	65	55	50	40	4 Yd³
2.3 m³	155	100	95	60	50	40	35	30	3 Yd³
1.5 m³	100	65	60	40	30	25	25	20	2 Yd³
0.76 m³	50	35	30	20	15	15	10	10	1 Yd³
Hauling Distance m	25	50	75	100	125	150	175	200	One way

❑ I.4   IDEAL OUTPUT OF THE TRACKED LOADER SHOVEL

Job Conditions. Assume digging maneuvering and dumping time as 0.4 min, speed (loaded) as 3 km/h and empty return as 6 km/h for an uninterrupted production.

Bucket Capacity	Output per hour in m³								Bucket Capacity
3.06 m³	260	185	140	115	95	85	75	60	4 yd³
1.53 m³	130	90	70	60	50	40	35	30	2 yd³
0.76 m³	65	45	35	30	25	20	15	15	1 yd³
Hauling Distance m	10	20	30	40	50	60	70	80	One way

❑ I.5   EXCAVATING AND LIFTING EQUIPMENT IDEAL OUTPUT PER HOUR IN BULK VOLUME IN EASY TO DIG SOIL SWING 90 DEGREE WITH 23 SECONDS CYCLE, UNINTERRUPTED PRODUCTION

Job Conditions: Easy to dig soil swing 90 degree with 23 seconds cycle uninterrupted production.

Types of Equipment	Features		Bucket Struck Capacity						
	Bucket Size	yd³	0.50	0.75	1.00	1.25	1.50	2.00	3.00
		m³	0.38	0.57	0.76	0.96	1.14	1.53	2.30
	Engine HP (Approx.)		50	75	100	100	130	160	200
1. Face Shovel	Maximum Cutting Height	m	7.0	7.0	7.0	7.0	7.5	8.5	10.0
	Ideal Output/hr (Loose, easy dig)	Lm³	60	90	120	150	180	220	300
2. Backhoe	Maximum Digging Depth	m	5.0	6.5	7.5	7.5	8.0	9.0	9.0
	Ideal Output/hr (Loose, easy dig)	Lm³	48	72	96	120	144	176	240
3. Dragline	Maximum Boom Length	m	21	21	21-27	21-27	21-27	27-30	30-33
	Ideal Output/hr (Loose, easy dig)	Lm³	45	67	78	113	135	165	225
4. Camshell	Maximum Boom Length	m	21-27	21-27	21-27	21-27	21-27	21-27	30-33

Ideal Output/hr (Loose, easy dig)	Lm³	24	36	48	60	72	88	120

❑ I.6   SCRAPPER IDEAL OUTPUT PER HOUR IN BULK VOLUME IN EASY TO SCRAP SOIL

I.6.1   Ideal Output of the Towed Scraper

Job Conditions. Assumed loading, maneuvering and dumping time as 3.0 min, speed (loaded) as 3 km/m and empty as 6 km/h, uninterrupted production.

Heaped Capacity	Output per hour in m³						Heaped Capacity
21.4 m³	215	140	105	85	70	60	28 yd³
18.4 m³	185	120	95	75	60	50	24 yd³
13.8 m³	140	90	70	55	45	40	18 yd³
10.7 m³	105	70	50	40	35	30	14 yd³
6.9 m³	70	50	35	30	25	20	9 yd³
Hauling Distance m	100	200	300	400	500	600	One way

I.6.2   Ideal Output of the Motorised Scraper

Job Conditions. Assumed loading, maneuvering and dumping time as 2.0 min. Rolling resistance of haul road is <5%, speed (loaded) as 20 km/h and empty as 40 km/h, uninterrupted production

Heaped Capacity	Output per hour in bulk volume m³										Heaped Capacity
38.3 m³	600	410	350	310	250	225	210	190	170	150	50 yd³
30.6 m³	485	325	230	250	200	180	170	150	135,	120	40 yd³
22. 3 m³	360	245	210	185	150	135	125	115	100	90	30 yd³
15.3 m³	240	165	140	125	100	90	85	75	65	60	20 yd³
Distance m	400	800	1000	1200	1600	1800	2000	2200	2600	3000	One way

❑ I.7   CORRECTION MULTIPLIER

I.7.1   Performance Factor

Job Conditions	Management Conditions			
	Excellent	**Good**	**Average**	**Poor**
Favourable	1.0	0.9	0.8	0.7

Average	0.9	0.8	0.7	0.6
Unfavourable	0.8	0.7	0.7	0.5

Note:

1. Management conditions, under control of management include operators' efficiency, equipment operation worthiness, equipment maintenance capability, planning and supervision effectiveness, client attitude etc.
2. Job conditions, which affect efficiency but are beyond the control of management cover terrain, weather conditions, temperature etc.

I.7.2 Common Correction Factors

1. Soil Factor, Multiply

Easy Dig (loam, sand, gravel) 1.00	Medium Dig (common earth) 0.85	Hard Dig (Stiff, slay, soft rock) 0.67

2. Swell Factor for in-place volume conversion, divide

Common earth 1.2	Sand and gravel 1.1	Clay (dry) 1.3

3. Altitude, reduce performance

0–300 m > 300 m	300 m and above Performance reduction altitude above 300 m	1% per 100 m increase in

Temperature derating effect, reduce performance

Temp C	0	15	30	45
Performance change %	+3	0	–3	–5

Equipment Performance Efficiency, Multiply

60 min	55 min	50 min/h	45 min	40 min/h
1.00	0.92	0.83	0.75	0.67

I.7.3 Correction Factors Special for Bull Dozer

Factor Multiply

S Blade	A Blade or P Blade	U Blade (used only in loose soil)
1.0	0.65	1.20

Transmission system Factor Multiply

Power Shift	Direct drive
1.0	0.8

Grade Factor (Approximate), Multiply

Up Grade	Down Grade
$1 - \dfrac{2.5 \, Grade\%}{100}$	$1 + \dfrac{2.5 \, Grade\%}{100}$

I.7.4 Correction Factors Special for Excavators

Soil Conversion Factor	Easy Digging	Medium Digging	Hard Digging				
	1.0	0.85	0.67				
Swing Factor	45	60	75	90	120	150	180
Angle of swing (degree) Factor	1.25	1.15	1.05	1.0	0.90	0.80	0.70

Load Factor

Side Casting	Loading in Vehicles
1.0	0.8

I.7.5 Correction Factors Special for Scrapers

Maximum Load Carrying Capacity = Weight of volumetric capacity, or Scraper pay load, whichever is less

Selecting Construction Equipment

The usage of equipment for accomplishing construction tasks is increasing rapidly. Plant and equipment now constitute a substantial portion of the construction costs in a project. The cost component depends upon the nature of the project and the extent to which equipment is employed. In a mechanised building project, the equipment costs can vary from 5% to 10% of the direct costs, whereas, in highway construction projects, the plant and equipment costs may reach as much as 40% of the project's direct costs.

To quote examples, the types of major construction equipment that is employed by two contracting companies, which are managed by India, engaged in the construction of building complexes are tabulated in **Exhibit 10.1**. One of these companies was working on the construction of a township project that costs over US $160 million in Iraq, and the other was engaged in executing multi-projects totaling about US $100 million spread over the United Arab Emirates. Each company was handling a peak workload of around US $5.0 million per month.

Equipment purchase involves initial heavy investments. In the long run, equipment adds up to the profitability by reducing the overall costs, provided that the equipment is properly planned, technically scrutinised, economically procured, and effectively managed. Poor selection and bad management of equipment are generally attributed to task mismatch, unplanned requirement forecasts, hasty purchase decisions, inadequate supply of repairs and spares, and lack of preventive maintenance.

This chapter deals with factors influencing the selection of equipment. It is divided into the following sections:

1. Task considerations
2. Cost considerations: Method of evaluation of equipment owning and operating costs
3. Equipment engineering considerations
4. Equipment acquisition options
5. Summary of equipment selection considerations

Exhibit 10.1

Housing Construction Project/Major Plant and Equipment Owned by Contractors

			$160M Project	$110M Project
I	**Earthmoving Machinery**			
	(1)	Dozers	2	
	(2)	Loaders Shovels	7	5
	(3)	Excavators	3	1
	(4)	Compressors	8	3
	(5)	Soil compactors	30	12
II	**Concreting Machinery**			
	(1)	Batching plants 35 m³	2	1
	(2)	Transit mixers 6 cm	4	3
	(3)	Concrete pumps	1 (Mob)	3 (Stationary)
	(4)	Concrete mixers 21/4	3	2
	(5)	Screed pumps	4	1
	(6)	Cement bag cutters	2	1
III	**Erection and Handling Machinery**			
	(1)	Cranes 55 Tons	4	1
	(2)	Cranes 20 to 35 tons	4	3
	(3)	Cranes 6 to 10 tons	3	2
	(4)	Forklifts	12	7
	(5)	Tower cranes		17
IV	**Transport Fleet**			
	(1)	Heavy duty tractors/tippers/dumpers/tankers	35	30
	(2)	Dumpers 2 ton capacity	16	7
	(3)	Form tractors with trailors	5	4
	(4)	Water/fuel tankers	3	2
V	**Power Generation and Water Supply Machinery**			
	(1)	Generators 500 KVA	1	
	(2)	Generators 175 KV A	10	
	(3)	Generators 25 to 55 KVA	6	12
	(4)	Pumps	7	39
VI	**Precast Factory Machinery**			
	(1)	Batching plant 100 m³/hr	1	–

(2)	Gantry cranes	10	–
(3)	Steam boilers	2	–
(4)	Moulds–vibratory	75	–
(5)	Electric cars	4	–
(6)	Prime movers for trailors	5	–
(7)	'A' frame trailors	10	–
(8)	Flat head trailors	5	–
VII	**Manufacturing Machines**		
(1)	Duct making	10	2
(2)	Inserts manufacturing	20	
(3)	Metal–work fabrication	7	4
(4)	GRC manufacturing	9	
(5)	Plastic moulding	2	
(6)	Wood–work and carpenter	15	36
(7)	Steel doors and windows	13	
(8)	Rebar fabrication	8	31
(9)	Block making	1	1
(10)	Spraying and plastering	6	7

Note: The $160 million project involving turn-key construction of a residential complex, containing 2000 dwelling units made of pre-cast concrete, shopping, social activity buildings, and connected external utility services. On the other hand, the $110 million project consisted mostly of administration building complexes in various cities, its earth-work, and utility services were mostly executed through sub-contracts. Plant and machinery employed on roadwork, is not included in the above list.

❑ 10.1 TASK CONSIDERATIONS

The task objectives at construction sites are stated in terms of nature of the task and the quantity of work that needs to be accomplished economically, within stipulated time and quality specification, and under given site conditions.

The nature of the task, dictates the type of equipment needed, while, the time allowed in the work schedule determines the rate of work. This rate of work indicates the output capability of the required equipment. The equipment productivity determines its cost effectiveness.

10.1.1 Nature of Work

The nature of production tasks in building construction projects, which can be performed with equipment, include excavating, hauling, transporting, filling, compacting, grading, fabricating, hoisting, concreting, pre-casting, block making, plastering, finishing, trenching, pipe-laying, cable-laying, road-making and so on. Generally, special purpose equipment is available for each of these

tasks. In addition, the support equipment at the project site consists of generators, pumping sets, treatment plants, and other utility services equipment.

10.1.2 Rate of Daily Output

The forecast of the quantity of work that is to be completed in a specified period conforming to the schedule of work, under given job conditions, defines the rate of daily output and the peak production level. Since, the primary purpose of having equipment is to achieve task objectives; the output of the equipment under site conditions will have to be equal to or more than the planned hourly rate at which the task is to be executed economically. In order to cater for occasional peak fluctuations, suitable means of expediting work, such as overtime working or inducting hired machinery will have to be examined.

10.1.3 Equipment Output Capability

The assessment of equipment's performance needs experience. The equipment capability to perform an assigned task under a given site situation, can best be determined either from the on-site actual trials or assessed from its past performance records of operation under similar site conditions. But at the equipment selection stage, the actual on-site trials may not be feasible, and the past performance data may not be always available, or it may not be adequate as the site conditions vary from place to place and project to project. In the absence of the reliable data, the equipment output norms can be derived from the performance data given in the manufacturer's manuals. These manuals outline the equipment's hourly output for a given task under ideal conditions. These ideal output norms can be suitably modified to conform to site conditions, by computing the performance efficiency factor.

Equipment standard hourly output = Ideal output per hour
× Performance efficiency factor × Correction factor

The equipment's performance at the worksite depends upon many situational factors that influence the output. These situational factors may include the equipment service conditions, the effect of terrain, the accessibility to worksite, working space restrictions, weather conditions, working conditions including timings, logistics, and equipment vendor support, and the availability of local resources like operators, equipment renting facilities, power and water supply, fuel and lubricants, etc. In order to simplify this evaluation for off the job initial planning purposes, the prominent situational factors, other than those considered while computing equipment output norms, can broadly be grouped under two headings, viz. (a) controllable factors and (b) uncontrollable factors.

Controllable factors.   These are factors, the effect of which can be controlled by the site management. The prominent contributing factors include but are not limited to the following:

- Equipment operational worthiness;
- Operator's skill to operate the machine effectively for performing the given task;

- Available facilities for repair and maintenance equipment;
- Planning and supervision effectiveness; and
- Level of motivation.

It is difficult to quantify the effect of the above controllable factors on the operation of the equipment, but the resultant effect of these can be conceptualised by assessing percentage operating efficiency of each and then calculating average of these to evaluate the overall grade.

Average (%)	Grade
80–100	Excellent
70–79	Good
60–69	Average
50–59	Poor

To quote an illustration, consider the following assessment of the controllable factors that are indicated by an experienced plant engineer:

Equipment worthiness	90%
Operator's skill	80%
Repair and maintenance facilities available	60%
Supervisory effectiveness	70%
Mean operating performance	75%
Average performance	75%

Therefore, the performance efficiency on account of controllable factors can be termed as 'Good'.

Uncontrollable factors.   These are the environmental factors over which the site man-agement has no control. These factors include terrain, weather, prevailing temperature, etc. The expected performance efficiency for each of these causes can be assessed and categorised as 'favorable', 'average', or 'unfavorable'.

Environmental conditions	Efficiency
Favorable	80%–100%
Average	60%–79%
Unfavorable	40%–59%

In particular, the effect of altitude and temperature on the performance of heavy equipment can be determined as under:

a.   *Effect of altitude on the performance of the engine*: With the increase in altitude, the density of air reduces and consequently the quantity of oxygen available in a given volume of air becomes less. This affects the air-fuel ratio, and in turn the engine power is reduced. The extent of reduction in power with the rise in altitude is given in the manufacturer's engine

performance specifications. In the absence of this, it can be assumed that for four-cycle diesel engines and all internal combustion engines, the engine efficiency and consequently the ideal output reduces at the rate of 1% for every 100 meters increase in altitude after 300 meters altitude above the sea level.

Altitude	Reduction percentage
0–300 m	No loss
Above 300 m	1% per 100 m increase in altitude above 300 m

Note: The effect of power loss can be eliminated by the installation of supercharges.

Example: Determine the resultant efficiency of a crawler tractor that is employed in cutting and leveling in an area at altitude of 2400 m.

$$\text{Efficiency at 2400 m attitude} = 100\% - (2400 - 300)/100 = 79\%$$

b.   *Effect of temperature*: The temperature at the place of work is responsible for change in the performance of a four-cycle diesel engine (specially the internal combustion petrol engine) from its standard conditions. This change can be assumed as under:

Temperature (C°)	0	15	30	45
Performance change (%)	−3	0	+3	+5

Overall Performance efficiency-factor.   The performance efficiency resulting from various controlled and uncontrolled factors can be determined as follows:

$$\text{Performance efficiency factor} = \text{Controllable Factor} \times \text{Uncontrollable Factor}$$

The approximate value of the performance efficiency factor can be determined from **Table 10.1**.

Table 10.1

Performance Factor Matrix

Uncontrollable Factors		Controllable Factors			
		Excellent	Good	Average	Poor
Environment multiplier		1.00	0.75	0.65	0.55
Favourable	0.90	0.90	0.70	0.60	0.50
Average	0.70	0.70	0.55	0.45	0.40
Unfavourable	0.50	0.50	0.40	0.35	0.30

The equipment efficiency, thus determined can be either expressed as a fraction or percentage or it can be stated in terms of effective time, which is represented in minutes per hour. For example,

the efficiency factor of 0.6 can be stated as 60% or 36 minutes effective output of hourly optimum production rate.

It may be noted that the given piece of equipment does not operate in isolation. Generally, it follows a sequence, i.e. one machine is followed by the next machine or related activity. Thus, the performance of equipment influences outcome of the subsequent equipment or activity. The standard output of a machine, therefore, has to be viewed in the light of the system and adjustments made if required, as any imbalances in related activity will adversely affect the overall output of the system.

10.1.4   Equipment Productivity

Equipment productivity is a measure of equipment's performance. It is expressed as the output achieved per equipment hour. The higher the output, the better is the productivity. A givenpiece of equipment's productivity is optimum, when it is employed on the primary task for which it is designed. For example, a bulldozer is most productive when it is used for cutting earth and hauling by dozing action up to 60 meters. In case, an equipment is to be used for secondary tasks, its optimum productivity will have to be multiplied by the Task efficiency factor, as illustrated for excavating machinery in **Table 9.2**.

10.1.5   Future Use of Equipment

If all expenses connected with the ownership and operation can be amortised on the project on which it is to be employed, there is no need to consider the future use of the equipment. However, if the equipment is to be utilised only for a part of its economic life in the project, the cost recovery on its balance life will have to be considered in terms of future use or disposal after part use. This involves evaluation of the equipment's owning and operating costs.

❑ 10.2   COST CONSIDERATIONS: METHOD OF EVALUATION OF EQUIPMENT OWNING AND OPERATING COSTS

The economic use of equipment is related to its employment cost. Hourly plant employment cost forms the basis for the cost estimation of work that is executed by the plant. The plant employment cost can be determined by computing plant owning and operating costs, as follows:

Equipment employment cost = Owning cost + Operating cost.

There are many factors, determinate as well as indeterminate, which affect the plant owning and operating costs. Some of these factors include the state of the plant (old or new) and its capitalised cost, the source through which the capital is to be raised in case of a new purchase, the site delivered price, the implication on corporate taxes for the new purchase, the company's policy regarding capitalisation, the economical plant life in years, the re-sale value after a useful life, the number of hours of operational employment contemplated in a year, the past performance records in the case of an old plant, the job conditions, the skill of the operator, and the repair and maintenance facilities including timely supply of spares.

The main factors affecting the owning and operating costs are explained below. These are followed by a simplified approach along with examples for estimating these costs. There is no substitute for experience, while, evaluating the plant employment costs. Therefore, the estimation method of the hourly plant cost given in succeeding paragraphs should be treatedas guidelines, which is to be modified by the experienced estimator according to the situation.

10.2.1 Equipment Owning Costs

It represents the cost of ownership for the equipment. These costs are incurred by the owner, whether, the equipment is used or not. The equipment owning costs include: (a) Depreciation cost, (b) Cost of capital invested and (c) Taxes and insurance.

Depreciation cost Depreciation is defined as the loss in market value of the plant over a period of time, resulting from its usage, wear and tear, or age.

There are several methods of calculating the annual depreciation that should be charged to the project for covering the plant capital cost. These include the straight line method, declining fund method, sum of digit method, and experience of owning and operating a similar plant. Depending upon the company policy, market trends and nature of usage, an appropriate method of depreciation can be adopted.

The commonly used methods are illustrated with an example of a crawler tractor. Its purchase price is $100 000 and the assessed re-sale value after using for 5 years is 10% of the delivered price. This equipment is planned to operate 2000 hours per year.

1. Straight-line Method. The straight line method is most commonly used for estimation of depreciation. It pre-supposes that equipment value reduces at a uniform rate over its economical life period. The information required is delivered-at-site price including attachments, the residual or re-sale value after use, and the equipment's usage life period. The tyre replacement cost is not included in the depreciation estimation, as it is dealt under operation costs.

$$\text{Annual depreciation} = \frac{\text{Delivered price } - \text{ Residual value}}{\text{Ownership period in years}}$$

$$\text{Depreciation per usage hour} = \frac{\text{Annual depreciation}}{\text{Usage per year}}$$

Example of crawler tractor:

$$\text{Delivered price} = \$100000.$$
$$\text{Residual value } = 10\% \text{ of } \$100000$$
$$= \$10000.$$

$$\text{Annual depreciation} = \frac{\$100,000 - \$10,000}{5 \text{ Years}}$$

$$= \$ \, 18,000$$

$$\text{Hourly depreciation} = \frac{\text{Annual Depreciation}}{\text{Usage hours per year}} = \frac{= \$18000}{2000} = \$9.00$$

2. Declining Balance Method.   This provides means of accelerating depreciation for tax purposes

(a) $\text{For new equipment, annual depreciation} = \dfrac{2.0 \times \text{Remaining book value}}{\text{Economic life}}$

(b) $\text{For old equipment, annual depreciation} = \dfrac{1.5 \times \text{Remaining book value}}{\text{Economic life}}$

Example of crawler tractor.   In the above formulae, the remaining book value = original delivered price – Accumulated depreciation

$$\text{First year depreciation} = \frac{2.0 \times 100,000}{5} = \$40,000$$

$$\text{Second year depreciation} = \frac{2.0(100,000 - 40,000)}{5} = \$24,000$$

$$\text{Third year depreciation} = \frac{2.0(100,000 - 40,000 - 24,000)}{5} = \frac{2.0 \times 36,000}{5} = \$14,400$$

$$
\begin{aligned}
\text{The book value at the end of 3rd year} \quad &= \text{Delivered Price – Depreciation charged} \\
&= 100,000 - 78,000 \\
&= 23,000
\end{aligned}
$$

$$\text{Fourth year depreciation} = \frac{2.0(100,000 - 78,400)}{5} = \frac{2.0 \times 21,600}{5} = \$8,640$$

$$
\begin{aligned}
\text{The book value at the end of 4th year} \quad &= \text{Delivered Price – Depreciation charged} \\
&= 100,000 - 40,000 - 24,000 - 14,400 - 8,640 \\
&= 14,960
\end{aligned}
$$

$$
\begin{aligned}
\text{Since the salvage value at the end of 5th year} \quad &= \; 10,000 \\
\text{Therefore depreciation after 5th year} \quad\quad\quad &= \; 14,960 - 10,000 = 4,960
\end{aligned}
$$

Hourly depreciation during the year can be calculated by dividing annual depreciation by usage hour i.e. 2000 hours.

Table 10.2

Annual and Hourly Depreciation and Residential Value of Equipment

Period	Annual Depreciation ($)	Residual book value ($)	Hourly Depreciation ($)
On receipt	Nil	100,000	
End of first year	18,000	82,000	9.00
End of second year	18,000	64,000	9.00
End of third year	18,000	46,000	9.00
End of fourth year	18,000	28,000	9.00
End of fifth year	18,000	10,000 (Salvage value)	9.00
Total amount depreciated	90,000	Salvage value = 10,000	—

3. Sum-digit method. It enables charging higher depreciation in the first year and reducing gradually in subsequent years. Depreciation by this method, for the crawler tractor, referred above, costing $100000, can be evaluated as under:

Sum of digit in 5 years life = $5 + 4 + 3 + 2 + 1 = 15$
Depreciation first year = 5/15 (Delivered Price – Residual Value)
Depreciation first year = 5/15 (100,000 – 10,000) = $ 30,000
Depreciation second year = 4/15 (100,000 – 10,000) = $ 24,000
Depreciation third year = 3/15 (100,000 – 10,000) = $ 18,000
Depreciation fourth year = 2/15 (100,000 – 10,000) = $ 12,000
Depreciation fifth year = 1/15 (100,000 – 10,000) = $ 6,000
Total depreciation charged at the end of fifth year = $ 90,000
And the salvage value at the end of 5th year = 10,000

Hourly depreciation during the year can be calculated by dividing annual depreciation by usage hour i.e. 2000 hours.

Note: When assessing the value of re-sale after a given period, it is essential to consider the local conditions and the physical condition of the equipment, depending upon the types of job and operating conditions.

The economical life of the equipment is difficult to determine because of inherent variables that affect the plant operation. For example, a sound preventive maintenance programme can add to the equipment's life by a considerable amount. Generally, an indication about the life of the plant can be obtained from the manufacturers, which can be modified depending upon the job conditions as illustrated in **Table 10.3**.

Investment Costs. These costs cover interest on the money that is invested in equipment/plant, taxes, insurances, licenses, and storage expenses. Rates for these costs vary with owners and loca-

Table 10.3

Assessment of Equipment Life in Operating Hours

Type of equipment	Favourable conditions	Average conditions	Unfavourable conditions
Crawler tractor	15000	12000	10000
Scraper	16000	12000	8000
Front–end–Ioader	12000	10000	8000
Dumper	25000	20000	15000

tions. However, these costs can be estimated on the basis of prevailing rates at the project location using the following formula:

$$\text{Average investment} = \frac{P + (P - S)/n + S}{2} = \frac{P(n + 1) + S(n - 1)}{2n}$$

Where,

P = Initial delivered cost

S = Salvage value after n years

When 'S' is small, $\dfrac{S(n-1)}{2n}$ becomes negligible, then 2*n*

$$\text{Hourly investment} = \frac{(N + 1) \times \text{Delivered price} \times \text{Annual interest rate etc.}}{2N \times \text{Annual usage hours}}$$

$$= \frac{(N + 1)\text{Delivered price} \times i}{2N \times \text{Annual usage hours}}$$

Where,

N = Ownership years

i = Rate of interest + insurance + tax.

In the crawler tractor mentioned above, consider the prevailing rates of interest as 16%, taxes 2%, and other expenses as 2%. The total effect of the investment costs of equivalent prevailing rates works out to be 20%. Averaged hourly investment costs using straight line depreciation method can be calculated as under:

$$\begin{aligned}
\text{Hourly Investment Cost} &= \frac{(N + 1)\ \text{Delivered price} \times i}{2N \times \text{Annual usage hours}} \\
&= \frac{(5 + 1) \times \$100{,}000 \times 20\%}{2 \times 5 \times 2000} \\
&= \$6.00
\end{aligned}$$

Note:It is a common practice to consider insurance, taxes, and storage expenses, as a percentage of the yearly average investment and then calculating the investment expenses considering the cost of interests, insurances, taxes, and storage, as total percentage expenses of the average investment.

10.2.2   Equipment Operating Costs

The cost of operating the equipment/plant includes fuel costs, routine maintenance costs, major repair costs, operators' costs, tyre replacement costs, and overhead costs.

Fuel costs.   Most of the construction plants at project sites use combustion ignition engines as the prime mover, which require fuel. The requirement of fuel at full load can be estimated from the engine flywheel horsepower BHP rating.

Cost of fuel consumed in one hour = Cost per litre × Hourly fuel consumption.
Hourly fuel consumption = Hourly fuel consumption at full load × Operating factor.

The fuel price per litre, delivered at the site, is obtained from the local suppliers as it varies from place to place. The rate of consumption depends upon the type of engine (diesel or petrol), the state of the engine and the working conditions. The assumed fuel consumption per hour in litres for a given HP engine is given below:

a.   Diesel engine fuel consumption per hour = 0.15 litres × rated HP × load factor.
b.   Petrol engine fuel consumption per hour = 0.22 litres × rated HP × load factor.

The load factor depends upon the operating conditions, as the equipment does not continue its working at full load for long. For example, a front-end-loader may operate at maximum power at the time of filling a dumper, for 6 seconds out of a cycle time of 30 seconds. Further, a loader may work for an average of 50 minutes in one hour and for the remaining time the operator may rest or load fuel. These operating factors are determined from experience or from equipment manuals. Typical equipment operating factors under various operating conditions for some of the earth moving plants are shown in **Table l0.4**.

For example, the hourly fuel consumption of a crawler tractor rated with 250 flywheel HP, operating under average conditions (load factor 70% from **Table l0.4**) and diesel costing $0.3/litre (assumed), can be worked out as under:

Diesel consumption per hour = 0.15 × Rated flywheel HP × Load factor
= 0.15 × 250 × 0.7 litres
= 26.25 litres

Cost of hourly consumption = Diesel consumption × Rate of diesel per litre
= 26.25 litres × $0.3
= $7.88

Routine maintenance costs.   Maintenance costs include the cost of lubricating oil, grease, filter, batteries, minor repairs, and labor involved in performing the maintenance work. The

Table 10.4

Load Factor

Equipment	Operating Conditions		
	Favourable	**Average**	**Unfavourable**
Crawler tractor	60%	70%	80%
Scrapper–self loader	48%	55%	65%
Scrapper–push loader	40%	50%	60%
Front–end–loader	35%	45%	55%
Bottom dumper	30%	40%	50%
Hauler	25%	35%	45%

quantity of lubricating oil that is required for lubrication can be calculated from the manufacturer's manual showing the number of hours after which the changing of oil is needed. Depending upon the operating conditions, the changing of oil generally varies from 50 to 200 engine running hours. Generally, the maintenance costs including service, labour (mechanic) cost and minor repairs, vary with the type of equipment involved and the project environment, which can be approximately calculated as proportion of hourly fuel cost as follows:

Operating conditions	Hourly maintenance cost
Favourable	1/4 Fuel cost
Average	1/3 Fuel cost
Unfavourable	1/2 Fuel cost

Major repair costs.   These costs vary with the type of equipment, the condition of the plant, vthe prices of spare parts, the maintenance charges, and the operating conditions. Generally, the cost of repairs that include cost of spare parts and labour, can be roughly taken as equal to the depreciation cost multiplied by repair factors. For special purpose equipment, such as the rock-crushing plant, the wear and tear is more, which needs detailed estimation. Similarly, for electrically operated plants, such as the concrete weight-batching and mixing plant, the repair cost is less than the depreciation cost.

Repair cost = Depreciation cost × Repair factor

Equipment type	Repair factor with operating conditions		
	Favourable	**Average**	**Unfavourable**
Crawler equipment	85	90	95
Scraper	85	90	105
Wheeled equipment	50	60	75

Repair costs vary appreciably with the age of the equipment. The repair cost in the first year of acquiring the new equipment is far less ac compared to repair cost in the fifth year of its operation. An approximate year-wise repair cost can be estimated by using the following relationship:

$$\text{Repair cost during } n^{th} \text{ year} = \frac{n \times \text{Value to be depreciated}}{\text{Digit sum of equipment's life in years}}$$

For example, if the total depreciation value of a wheeled equipment (repair factor = 0 .75) works out as $75 000 and its life is 5 years, then the repair cost during each year of operation (working 2000 hours per year) can be estimated as under:

$$\text{Total repair cost} = \text{Total depreciation} \times \text{Repair factor}$$
$$= \$75\ 000 \times 0.75$$
$$= \$56\ 250$$

Operation year	Annual repair cost	Hourly repair cost
1	56 250 × 1/1 + 2 + 3 + 4 + 5 = $3750	3750/2000 = $1.875
2	56 250 × 2/1 + 2 + 3 + 4 + 5 = $7500	7500/2000 = $3.750
3	56 250 × 3/1 + 2 + 3 + 4 + 5 = $11 250	11 250/2000 = $5.625
4	56 250 × 4/1 + 2 + 3 + 4 + 5 = $15 000	15 000/2000 = $7.500
5	56 250 × 5/1 + 2 + 3 + 4 + 5 = $18 750	18 750/2000 = $9.375

Manpower cost. Equipment requires operators, drivers, and helpers for its operation. The equipment operators are highly skilled persons. The number of persons working on equipment varies with the type of equipment. A dumper may have only one driven-cum-operator, whereas, a bulldozer will need an operator and a helper. Some companies employ operators on a regular basis as they generally remain with the equipment even when it is idle. Depending upon the persons required per machine, the prevalent wage rates, the facilities provided by the company, and the hourly manpower costs can be calculated, as shown in **Table 11.3**.

Tyre costs for wheeled equipment. It is not easy to forecast the tyre life due to a large number of interacting variables. In fact, there is no accurate method of determining thetyre life. The tyre manufacturers provide indication of tyre life but these should be taken as guidelines only. The tyre life should be assessed by experienced plant engineers. In the absence, of such a facility, **Table 10.5** following can be used to estimate life of a tyre:

10.2.3 Method of Estimation of Owning and Operating Costs

Hourly owning and operating cost of equipment can be calculated, moving step by step, as listed in **Exhibit 10.2**. This Exhibit contains two solved examples of a crawler tractor and a pneumatic tyre dump truck. The step-by-step approach followed is self-explanatory.

Table 10.5

Estimation of Tyre Life of Wheeled Equipment

Equipment	Favourable Hours	Average Hours	Unfavourable Hours
Scraper (twin tractor)	4000	3000	2500
Scraper (single tractor)	4000	3000	2500
Scraper	5500	3500	2500
Loader	4000	3000	2000
Dumper	4000	3000	2000

The **Exhibit 10.2** includes the example of a pneumatic-wheeled diesel engine dumper (engine rated HP 215), purchased for a delivered price of $80 000, with an assessed life of 8 years, and while working under average operating conditions, at planned working of 1500 hours per year. The residual value at the end of 8 years is 20%. Depreciation is being charged on an annual basis. The overall equivalent annual expenses are interest (16%), taxes (2.0%), and other expenses (2.0%). Its tyre replacement cost is assessed as $4000 and its life is considered as 2000 hours.

Exhibit 10.2

Construction Equipment Costing Hourly Owning and Operating Cost Estimate

Ownership Data

Machine Nomenclature		Crawler	Dump
		Tractor(s)	Truck(s)
A.	Rated horsepower	250	215
B.	Ownership period (years)	5	8
C.	Estimated Usage (Hours/years)	2000	1500
D.	Ownership Usage (Total Hours) (Condition–Severe/Average/Moderate)	10,000	12,000
Owning Costs		Severe	Severe
E.	Delivered Price	100,000	80,000
F	Tyres Original Cost	Nil	4,000
G.	Delivered price less tyres (E – F)	100,000	76,000
H.	Residual Value at disposal (Expressed as % of G.) 25%	25,000	16,000
I.	Value to be Depreciated (G – H)	75,000	60,000

J.	Depreciation per hour (l/D)	7.50	5.00
K.	Interest Cost @ 16% per hour $\dfrac{B+1}{2B} \times \dfrac{E \times \text{Rate}}{D}$	4.80	4.56
L.	Taxes and Insurance @ 4% per hour $\dfrac{B+1}{2B} \times \dfrac{E \times \text{Rate}}{D}$	1.20	1.14.
M.	Owning Cost per hour (J + K + L)	13.50	10.70

Operating Costs

N.	Fuel (Consumption diesel = 0.15 litres × HP × Load factor)	7.88	6.78
O.	Oil, Lubricant, Filters etc. (N × Service factor) =N/3	2.63	2.26
P.	Tyre Replacement Cost (= F/tyre life)	Nil	2.00
Q.	Repairs (J × Repair Factor)	7.12	3.75
R.	Special Wears	Nil	Nil
S.	Total Operating Cost per hour (Sum of N to R)	17.63	14.79
T.	Total Owning and Operating Cost (M + S)	31.13	25.49

Manpower Costs

U	Operator Costs per hour	10.00	10.00
V.	Helpers Costs per hour	Nil	Nil
W.	Total Crew Cost per hour	10.00	10.00
X.	Total Owning and Operating Cost (T + W)	41.13	35.49

❑ 10.3   EQUIPMENT ENGINEERING CONSIDERATIONS

Construction equipment is manufactured according to the standard specifications. The manufacturer's specification sheets enumerate equipment's characteristics but these sheets only highlight the aspects, which the manufacturer wants the customer should know. These specification sheets hide more than what they reveal. In order to unfold hidden information, the manufacturers' manuals need to be studied critically, prior to making a selection. This critical examination varies with the type of equipment. For example, guidelines given below can be followed for studying some of the typical features of a piece of equipment.

10.3.1   Equipment Components Specially of Earthmoving Plant

Engine.   It is the most important component of the equipment. Its special features include:

1. *Horsepower rating*: The engine flywheel HP rating provides a measure of the engine power available. The engine performance can best be analysed by evaluating the available rim pull or drawbar power.
2. *Performance curves*: Since earth-moving equipment is subjected to heavy loads for short periods of time; the engine should be able to provide high torque at low engine speed (rpm). It is the flat portion of the torque curve that indicates its lugging ability.
3. *Maintenance*: In order to facilitate easy maintenance and repairs, the engine should be suitably located within the body as to minimise its interference with other parts. Its exterior should be clear of lines and clutters to enable easy access for servicing. Also, its exterior features should motivate operators to conduct routine maintenance tasks.
4. *Warranty*: The period and comprehensiveness of the manufacturers' warranty can be taken as an indicator for the soundness of quality. It is desirable that both, the engine as well as equipment warranty should be for the same period and their service is looked after by the same source.

Transmission.   Like the engine, transmission needs to be matched with the job requirement. Direct drive transmission comes in a variety of forms, starting from a simple gear mechanism to sophisticated full-range planetary power shift transmission. Direct drive transmission is considered to be the most efficient.

Brakes.   These should be able to withstand repetitive use without much wear and should be able to stop the equipment within a short distance. Hydraulically operated brakes are preferred to exposed brakes due to their characteristics, such as smooth braking action, less wear, and longer life.

Steering.   Power steering is preferred to manual or hydraulically boosted manual steering, due to the ease of operation. Power steering is particularly necessary for the wheeled loader and other wheeled equipment carrying heavy loads. Articulated power steering is now being employed to reduce turning circles (by literally bending the machine in the middle of long-wheel-base equipment such as motor graders,) so as to increase maneuverability and stability.

Operator's cabin.   Reduction in the operator's fatigue, while, at work can enhance his efficiency. Fatigue reduction can be achieved by making the operator comfortable with normal expenses. Some of the following operator's cabin features can improve the following working conditions:

- Adequate cabin size with high-strength glazed and shatter-proof windows to permit unrestricted visibility, which are fitted with air-conditioning devices to maintain a comfortable working temperature during all weathers;
- Fully adjustable suspension seats;
- Easily accessible and suitable separated control levers;
- Comprehensive, promptly-readable monitoring panels, indicators, and instrument gauges; and

- Skid-proof mounting arrangement and cabin surfaces to prevent slipping.

Carrier.   Equipment carriage mountings are of three types; crawler mounting, truck mounting, and wheel mounting. Crawler mounting is especially useful for weak pressure bearing soils. Crawler mounting exerts low ground pressure and can operate over soils having low bearing capacity. Tracks can be made extra wide if required to overcome the special low ground pressure condition and its links can be treaded, when increased traction is required. Because of their low speed, such as 3 km/hour, crawler mounted equipment is transported on trailers. Short movements, such as less than a kilometer, are possible on tracks, but travel in case of a highway is avoided in order to prevent damage to the pavement.

Truck mounting and wheel mounting make use of rubber tyres. These can move on wheels with speed. During movement they do not cause damage to the paved highway surfaces, but they cannot operate effectively on low ground pressure areas. The main difference between truck mounting and wheel mounting is that, while, the former requires separate engines for vehicular movement and equipment like crane operation; on the other hand, the latter uses the same engine for both purposes.

10.3.2   Standard Equipment

Standard equipment performs multipurpose tasks. Such items of equipment are manufactured by reputed firms and are easily available in the market. They can be utilised in other projects and can be sold easily when not required. They are also easily repairable. Unless a project justifies the purchase of special purpose equipment; preference is given to selecting standard equipment.

10.3.3   Minor Equipment

Items of equipment and tradesmen's machinery, each costing less than a value specified by the project management, say US $2000, can be considered as minor equipment. This includes plate compactors, impact vibrators, small pumps, power generators, workshop machinery like welding sets, tile cutting, and polishing machines, plastering and spraying machines, concrete scrubbing and finishing equipment, light-duty tradesmen's tools, and similar small sized equipment. Minor equipment frequently needs repairs. For minor equipment, stress is laid on standardisation and preference is given to those manufacturers, who have locally established dealers for spares and service, even if it amounts to pay a higher initial cost. If local service is not available, the need of having a stand-by minor equipment, should be given due weightage against the cost of stocking spares and remaining idle, while awaiting repairs.

10.3.4   Repair and Maintenance Considerations

After-sales service.   Despite due care, the parts in an equipment are subject to failure. Unless immediately replaced, a broken part can delay the entire operation. It is therefore, essential that

after-sales service like availability of repair facilities for spare parts , and after-sales consultancy should be ensured during selection of the equipment, by visiting the local dealer's/vendor's office, workshop, and other service facilities. In particular, equipment manufactured by a reputed firm should be preferred.

Standardisation of equipment. If a contractor owns equipment of a particular make and is satisfied with its performance and dealer's service; induction of the same make equipment can facilitate reduction in spares inventory, ease of repairs and maintenance, and speedy deployment of equipment.

10.3.5 Safety Features

The equipment is generally manufactured to conform to the safety regulations of the country. These regulations specify the measures that are necessary to meet minimum safety requirements. However, some of the manufacturers do provide additional safety features. The extent of these mandatory and additional safety features, vary with the types of equipment and the manufacturers. These should be studied prior to making a selection of the equipment.

❑ 10.4   EQUIPMENT ACQUISITION OPTIONS

A project has diverse activities, where plant can be employed effectively and efficiently, but this does not justify purchasing plant to perform all these activities. Purchase of plant requires a heavy investment of capital, where no contractor can afford the luxury of owning all types of plant and machinery that are required in a project. Contractors have a number of options for acquiring plant. These options include the following: (a) Purchasing plant, (b) Renting plant, (c) Leasing and hire purchase of plant and (d) Replacing old plant. There are many aspects, which are considered while taking a decision regarding the mode of acquiring plant. These aspects are outlined in the following subsections.

10.4.1   Purchasing Plant/Equipment

Outright purchase of plant requires heavy initial investment and is resorted to only, when it can yield a rapid rate of return. Any money spent on plant is considered as an investment that should recover the capital invested along with profit. At least, plant purchased must pay for its cost that is been incurred in the project. As a general guideline, contractors own only items, which are frequently required, have profit potential, yield quick adequate returns, and are absolute necessary for project operations. Further, merely owning plant is not enough; it must be adequately backed up by spares, repairs, and maintenance machinery.

There are two modes of payment for purchasing equipment, i.e. outright purchases by making full payment or credit purchases by making payments in agreed instalments. If the company has sufficient cash available, then an outright cash purchase saves interest and inconveniences of arranging sureties and guarantees. Credit purchase is less demanding on cash than outright purchase.

To quote an example, a concrete pump with cash sale price in Saudi Riyals (SR) of SR 1.54 million was offered by the sales agency on credit purchase basis for down payment of SR 114 000 at the time of delivery and the balance of SR 14 000 000 (plus interest) in 59 equal monthly installments of SR 33634 (see **Exhibit 10.3**).

Exhibit 10.3

Plant Leasing Offer of a Concrete Pump

Concrete Pump, PM Make, Model BSF 1409
Extracts From Leasing Offer By a Leasing Company

1. Lessor: XYZ Equipment Leasing Enterprise.

2. Lessee: ABT Construction Company

3. Equipment Particulars: Concrete Pump, PM make, Model BSF 1409, Year of manufacture 1990, Boom 36 metres, performance specifications and accessories as per manufacturer's manual and supplier's quotation.

4. Purchase Price: SR 1,540,000.00

5. Lease Maturity: 3 Years starting from delivery of equipment.

6. Rental Options: Payable Monthly or Quarterly (two options

Payment option	*No. of Instalments*	Amount per Instalment
Monthly	60	SR 33,634
Quarterly	20	SR 99,561

7. Purchase Options in–between leasing period:

Purchase Date by lessee	*Monthly Scheme*	*Quarterly Scheme*
After 2 Years	SR 1,052,401	SR 1,014,933
After 3 Years	SR 767,568	SR 750,568
After 4 Years	SR 443,926	SR 433,937
After 5 Years	SR 77,000	SR 77,000

8. Contract Other Terms: As mutually agreed.

Credit payments are time related. Time is money, money yields interest. Consequently, the time and the amount of instalment payments are extremely important to determine the present value of the deal. The present value of the expected future payment is calculated by discounting future cash in-flows using the following relationship:

$$PV = 1/(1 + k)^n$$

Where PV = Present value of $1 received at the end of n years at k% annual discounting rate. For example, the present value of $1 received after two years from now, when discounted at 10% annum, is given by

$$PV = 1/(1 + 0.1)^2 = 1/1.21 = \$0.83$$

Proceeding similarly, the present value of each instalment of the agreed mode of payment can be discounted to calculate the present value of the acquisition option. To quote an example, the present sale/purchase of equipment at an agreed price of $250 000, with down payment of $100 000 and balance payment in three equal yearly installments of $50 000 each, can be worked out as under:

PV = Down payment + Present value of First year instalment
+ Present value of Second year instalment + Present value of Third year instalment

Down payment		= **$100,000**
PV of first year instalment	$= \dfrac{\$50,000}{(1 + 0.1)^1}$	= $45,500
PV of second year instalment	$= \dfrac{\$50,000}{(1 + 0.1)^2}$	= $41,500
PV of third year instalment	$= \dfrac{\$50,000}{(1 + 0.1)^3}$	= $37,500
PV of the deal		$224,500

The equipment holding of a construction company conveys its strength. Equipment after purchase becomes an asset of the company. Ownership implies better care and maintenance of the equipment and the company can exercise full control over its deployment according to its need at various project sites. The owner has the option to dispose off the equipment, when itt is not required after job completion. Purchase of grants title for ownership of the acquiring company enables it to claim various tax reliefs/benefits of capital purchases. These include investment allowances, depreciation charges, and salvage values, as applicable.

However, in addition to initial heavy investment, equipment ownership has certain inherent disadvantages, as well. If not fully utilised, it is more expensive than renting. With the rapid improvement in technology, the equipment may become obsolete in due course. Further, equipment repairs and maintenance costs increases with the passage of time and the continuous use of old equipment may affect the contractor's profitability and ability to compete with others having more efficient equipment.

10.4.2 Hiring Equipment

Increasing short-term requirement of equipment by contractors and the heavy investment needed for its purchase has ushered in an era of equipment-renting companies. These companies provide a

wide range of equipment relieving contractors from the burden of stocking all the equipment and their spares. As, a general rule, contractors hire mobile expensive equipment for short periods of time in order to boost output, as and when required. An economic analysis could be made initially to decide whether, to purchase or hire the equipment or subcontract the work.

Consider, for example, a crawler tractor having 5 years' life with 2000 hours' employment capability per year and having the following associated costs:

a. Fixed cost/hour = $22 (Depreciation $17 + Other fixed $5)
b. Operating variable cost/hour = $35
c. Hire charges/hour = $90 (including operator, repairs, maintenance, etc.)

If the equipment is utilised for 'n' hours ($n < 2000$ hours) in the year, the contractor's yearly cost for either purchasing or hiring can be worked out as under:

$$\text{Ownership cost} = \$22 \times 2000 + \$35 \times n \qquad \text{(A)}$$
$$\text{Hiring Cost} = \$90\, n \qquad \text{(B)}$$

Therefore value of n for equal expenses on ownership and hiring basis can be obtained by equating A = B or

$$22 \times 2000 + 35n = 90n$$

or
$$n = 800 \text{ hours}$$

This calculation shows that it is economical to own the equipment if the operational requirement exceeds 800 hours, and owner contemplates full utilisation in subsequent years.

10.4.3 Leasing and Hire-purchase of Equipment

Both, leasing and hire-purchase imply the payment of hire charges regularly for an agreed period, with the option to buy the equipment at a pre-determined price after the specified period. Both the methods involve regular payments over an extended period of time but they are less demanding on the available cash than outright purchase.

When a piece of equipment is acquired on a lease basis, the ownership title remains with the leasing company, and the acquiring company cannot get the tax and other benefit of owning the equipment. It only uses it on payment of rent. In short, the lessor is the owner of the equipment and the lessee is its user. At times, the leasing company provides finance for the leased time (called primary period) to the equipment manufacturer, from whom then it is bought by the leasing company. Payments for the primary period is calculated by the leasing company after taking into consideration the capital cost of the equipment, less its resale value plus overheads and profit. The payment for the balance period, termed as the secondary period are negotiated. They are usually small as the primary period generally, covers other costs and profits. In particular, the leasing company makes the leases agreement with the acquiring company in such a way that the acquiring company is unable to cancel the agreement during the primary period. These agreements also specify the responsibility for insurance, maintenance, servicing, and repairs, so as to protect the leasing company's property

during the primary period. The leasing company, thus, acts as a financing company for the primary period. For example, an offer given by a leasing company to a contractor for a new concrete pump costing Saudi Riyal (SR) 1.54 million is shown in **Exhibit 10.3**. The offer is for two alternative-one involving a monthly installment, and the other a quarterly installment during the primary period of two years. The lessee has purchase offers commencing from the third year of leasing.

To a contractor, leasing provides certain advantages. Leasing does not involve incurring of initial costs and it does not carry the risk of obsolescence. It is also does not get affected with appreciation or depreciation of the prices, as the contractor does not have to look for re-sale. It enables the contractor to pay back as the work progresses and brings in returns. Leasing is generally advantageous to the lessor also, if its profit flow is comparatively small. It does not need tax exemption benefits of capital purchase. When the company's cash flow situation is unable to provide for the necessary funds or when the company is unable to arrange further borrowings for capital purchases; it is advantageous. Hire-purchase and leasing are similar as far as the regular rental payments are concerned but they differ in some ways. Generally, hiring companies provide operators, repair and spare services, whereas, the leasing companies do not. The hiring companies are equipment-holding companies, whereas, leasing companies are financing companies.

10.4.4 Replacing Equipment

Equipment once purchased needs not to be kept till it becomes unserviceable. In its useful life, every piece of equipment passes through a period of most economical operation and there is also a period when it ceases to be economical. It is at this uneconomical point of time that equipment should be considered for replacement. The replacement time is difficult to determine as it depends upon many cost factors, such as depreciation cost, investment cost, operations cost, down-time cost, obsolescence cost, inflation, and the new equipment purchase cost. Some of these cost computations require in-house records and equipment marketing experience. A replacement decision involves analysis of mathematical models incorporating a large number of variables. This analysis aims at determining the optimum time in equipment's life at which the equipment should be replaced for maximising profits or minimising operating costs. There are a number of methods for analysing the economics of equipment's replacement. A simple approach is to consider the resultant effect of replacement costs during each year of operation and identify the time, which corresponds to lowest cumulative cost per hour of operation. The typical replacement costs considered during the analysis are as follows:

1. *Depreciation cost*: The basis and method of determining depreciation is covered above. This determination of depreciation, which generally conforms to statutory requirements, should be modified to meet real life situations.
2. *Investment costs*: This includes the costs of capital invested and covers expenses like interest, taxes, and insurance. These costs can be assessed, say, as 15% of average investment.
3. *Down-time costs*: Generally, equipment breakdown increases with increase of equip-ment's age. During the breakdown period, substitute equipment has to be hired to maintain the

planned production. This additional cost, which is required to compensate for equipment breakdown time or poor performance, is termed as down-time cost.

4. *Obsolescence cost*: The sale price of an old equipment decreases with the induction of the latest versions reflects improved performance. The loss in value thus, suffered by an equipment is termed as obsolescence cost. It is expressed as a percentage of the original purchase price. At times, the obsolescence cost gets offset by inflationary tendencies and the differences between the original and re-sale value over a short period of time gets nullified.

5. *Replacement cost*: The replacement cost is the cost incurred for acquiring equivalent new equipment and disposing off the old one. Generally, the cost of owning new equipment increases at a rate higher than the inflationary trend.

The method of determining replacement costs is illustrated with an example of a front-end loader costing $100 000. The equipment is assessed to have a useful life of 12 000 working hours, and generally works for about 2000 hours per year. Analysis of the hourly effect of various costs, each considered separately, leads to the economical-operation time at which the plant should be considered for replacement.

The data tabulated in **Exhibit 10.4** illustrates the methodology adopted for evaluating various hourly costs affecting replacement decisions. These costs are depreciation, investment, downtime and obsolescence.

Exhibit 10.4

Equipment Replacement Decision Data

Code	Basic Data	Unit	Number of Years				
			1	2	3	4	5
A	Predicted sale–value (end of year)	$	75000	60000	45000	30000	20000
B	Assessed machine utilisation	Hrs	2000	2000	2000	2000	2000
C	Cumulative machine utilisation	Hrs	2000	4000	6000	8000	10000
	Deprecation Cost						
D	Yearly depreciation	$	25000	15000	15000	15000	10000
E	Cum depreciation	$	25000	40000	55000	70000	80000
F	Depreciation/hour (E/C)	$/hr	12.5	10.0	9.17	8.75	8.00
	Investment Cost						
G	Investment (beginning of year)	$	100,0000	75,000	60,000	45,000	30,000

H	Deduct depreciation	$	25000	15000	15000	15000	10000
I	Investment (G–H)	$	75000	60000	45000	30000	20000
J	Average investment	$	87500	67500	52500	37500	25000
K	Investment cost (15% per year)	$	13125	10125	7875	5625	3750
L	Cum investment cost	$	13125	23250	31125	36750	40500
M	Cum investment cost/Hr (L/C)	$/hr	6.56	5.81	5.19	4.59	4.05
	Down–time Costs						
N	Assessed availability (%)	$	97.5	95	92.5	90	87.5
O	Machinery not available (%)	$	2.5	5	7.5	10	12.5
P	Machinery not utilization	hrs	50	100	150	200	250
Q	Predicted hiring charges per hour	$/hr	30	32.5	35	37.5	40
R	Down–time cost	$	1500	3250	5250	7500	10000
S	Cum–down–time cost	$	1500	4750	10000	17500	27500
T	Down–time cost/hour (S/C)	$/hr	0.75	1.19	1.67	2.19	2.75
	Cost of Obsolescence on Performance						
U	–Assessed obsolescence (i)		–	5	10	15	20
V	–Shortfalls with respect to new model (T X B)	hr	–	100	200	300	400
W	–Hiring charges per hour	$	–	32.5	35	37.5	40
X	–Obsolescence costs	$	–	3250	7000	11250	16000
Y	–Cum obsolescence costs	$	–	3250	10250	21500	37500
Z	–Obsolescence cost per hour (Y/C)	$/hr	–	0.81	1.71	2.69	3.75
	Total replacement costs/hr (F + M + T + Z)	$/hr	19.81	17.81	17.74	18.22	18.55

Replacement decision: The summarised effect of costs tabulated in **Exhibit 10.4** indicates an approach to determine the most economical time when the equipment should be replaced. In the given Illustration, the cost analysis shows that the economical period for holding the equipment is the end of three years, and after this period, the old equipment can be considered for replacement.

❑ 10.5   SUMMARY OF EQUIPMENT
SELECTION CONSIDERATIONS

Selection of an equipment or plant system to perform an assigned task depends upon many inter-related factors. These factors are listed below:

Task Considerations

- Nature of task and specifications;
- Daily or hourly forecast of planned production;
- Quantity of work and time allowed for completion;
- Distribution of work at site; and
- Interference expected and interdependence with other operations.

Site Constraints

- Accessibility to location—Maneuverability at site;
- Working space restrictions;
- Altitude and weather conditions;
- Working season and working hours;
- Availability of local resources of manpower, materials and equipment;
- Availability of land, power supply and water supply for workshop and camp;
- Availability of equipment hiring, repair and maintenance facilities, locally; and
- Availability of fuel, oil and lubricants.

Equipment Suitability

- Type of equipment considered suitable for the task;
- Make, models and sizes of special purpose, and general purpose equipment available that can handle the task;
- Production capability, serviceability condition and delivery time of each equipment available; and
- Equipment already owned by the contractor—Usefulness of the suitable equipment available for other and future tasks.

Operating Reliability

- Manufacturer's reputation;
- Equipment components, engine-transmission, brakes, steering operator's cabin.
- Use of standard components;
- Warranties and guarantees;
- Vendor's after-sale service;
- Operator's acceptability, adaptability and training requirements;

- Structural design;
- Preventive maintenance programme;
- Safety features; and
- Availability of fuel, oil and lubricants.

Maintainability

- Ease of repair and maintenance;
- Vendor's after-sale service, repairs, spares and maintenance;
- Availability of spare parts; and
- Standardisation consideration.

Economic Considerations

- Owning costs;
- Operating costs;
- Re-sale or residual value after use; and
- Replacement costs of existing equipment.

Commercial Considerations

- Buy second-hand or new equipment;
- Rent equipment;
- Hire-purchase equipment; and
- Purchase or lease.

Equipment selection analysis considers various factors but not necessarily limited to the above. It leads to alternative choices for acquiring the required equipment. It is then for the management to make a selection decision of the equipment after careful consideration of all the facts. It may be noted that in most cases, the final equipment selection decision is likely to be a compromise between what is ideally required and what can actually be obtained economically. The characteristics and capabilities of some of the high-tech construction equipments are out-lined in Section 1.1.3.

APPENDIX J

Time Value of Money

❏ J.1   INTRODUCTION

Interest is the cost of using money. The value of money is linked with the time when it is received or paid, e.g. an investment in a bank fixed deposit of Rs. 100 today would grow to 100 + r in a year hence, where 'r' is annual rate of interest, which is represented in percentage. Similarly, in an inflationary period, a rupee today represents a higher real purchasing power than a rupee at the end of the year, as Rs. 100 received at the end of a year has less present value. The difference between the original amount and the roll forward accumulated amount is called compounded interest and the difference in the future amount and its present roll back value is called compounded discount. Accordingly, each cash transactions occurring at different points of time need adjustments for the time value of money. These adjustments involve determine the following:

- The future value of a single amount
- The future value of an annuity of equal amount;
- The present value of a future amount;
- The present value of an annuity of equal amount; and
- The present value of cash inflow of unequal amount and discount.

❏ J.2   FUTURE VALUE OF A SINGLE AMOUNT

Annual Compounding Period.   If the interest is compounded annually, then:

$$FV = PV(1 + r)^n$$

Where,

FV = future value n years hence

PV = present value

  r = interest rate per annum

 n = number of years compounded

Example: A bank deposit of Rs. 10 000 at 12 per cent interest that is compounded annually and invested for six years will become Rs. 19 738.23 on maturity. The future value six years hence can be calculated as follows:

- Calculate the future value using the formula

$$Rs. 10\ 000(1+0.12)^6 = Rs. 10\ 000(1.973823\ )$$
$$= Rs. 19\ 738.23$$

- Calculate the future value using **Table J.1**.

$$= \text{Rs. } 10\ 000 \times \text{Interest factor (from \textbf{Table J.1}.)}$$
$$= \text{Rs. } 10\ 000(1.974)$$
$$= \text{Rs. } 19\ 740$$

Table J.1

Future Value Interest Factor

Interest Factor $= (1 + r)^n$

Year Hence	1%	2%	4%	6%	8%	10%	12%	14%	15%	16%	18%	20%
1	1.010	1.020	1.040	1.060	1.080	1010	1.120	1.140	1.150	1.160	1.180	1.200
2	1.020	1.040	1.082	1.124	1.166	1.210	1.254	1.300	1.322	1.346	1.392	1.440
3	1.030	1.061	1.125	1.191	1.260	1.331	1.405	1.482	1.521	1.561	1.643	1.728
4	1.041	1.082	1.170	1.262	1.360	1.464	1.574	1.689	1.749	1.811	1.939	2.074
5	1.051	1.101	1.217	1.338	1.469	1.611	1.762	1.925	2.011	2.100	2.288	2.488
6	1.062	1.126	1.265	1.419	1.587	1.772	1.974	2.195	2.313	2.436	2.700	2.986
7	1.072	1.149	1.314	1.504	1.714	1.949	2.211	2.502	2.660	2.826	3.185	3.583
8	1.083	1.172	1.369	1.594	1.851	2.144	2.467	2.853	3.059	3.278	3.759	4.300
9	1.094	1.195	1.423	1.689	1.999	2.358	2.773	3.252	3.518	3.803	4.435	5.160
10	1.105	1.219	1.480	1.791	2.159	2.594	3.106	3.707	4.046	4.411	5.234	6.192

Shorter Compounding Period: If the interest is compounded more frequently, say four times a year, then the future value of Rs. 10 000 at 12% nominal interest at the end of six years can be calculated as follows:

$$FV = PV(1 + r/m)^{m \times n}$$

Where,

  $m = 4 =$ number of times compounding is done in a year.

  $n = 6 =$ number of years compounded

Therefore, in this case:

$$FV = \text{Rs. } 10\ 000\{1 + 0.12/4\}4 \times 6$$
$$= \text{Rs. } 20\ 328$$

Doubling Period: Its approximate value can be calculated using the following thumb rules:

a. Rule of 72 = Divide 72 by the interest rate
b. Rule of 69 = 0.35 + Divide 69 by the interest rate. This rule is more accurate than the 'Rule of 72'

EXAMPLES

Thumb rule	Formula	Interest rate (%)	Doubling period
Rule of 72	72/Interest rate	I. 12	72/12 = 6 years
	72/Interest rate	II. 10	72/10 = 7.2 years
Rule of 69 (More accurate)	0.35 + 69/Interest rate	III. 12	0.35 + 69/12 = 7.2 years
	0.35 + 69/Interest rate	IV. 10	0.35 + 69/10 = 7.25 years

❏ J.3 FUTURE VALUE OF AN ANNUITY OF EQUAL AMOUNT

An annuity is a series of periodic cash flows of equal amount. It can be payments or receipts.

$$FV_n = A\frac{[(1+r)^n - 1]}{r}$$

Where,

FV_n = Future value n years hence
A = Regular annual cash flow
r = Interest rate per annum
n = Period of annuity

Example: Calculate the value of Rs. 10 000 per year at the end of three years, deposited regularly at the start of each year in a bank account at 10% interest.

- Calculating the future value using the formula:

$$FV^n = \frac{A[(1+r)^n - 1]}{r} = 10000\frac{[(1+0.1)^3]}{0.10} = 10000(3.31) = Rs.33100$$

- Calculating the annuity interest factor using **Table J.2**, we get 3.31.

Therefore, future value of the annuity = 10 000(3.31) = Rs. 33 100

❏ J.4 PRESENT VALUE OF A FUTURE AMOUNT

Annual Discounting Period: For interest compounded annually, the present value is the inverse of compounding. The present value formula can be obtained as follows:

Now,
$$FV = PV(1 + r)n$$

Therefore,

$$PV = \frac{FV}{(1+r)^i}$$

Example. Find the present value of Rs. 10 000, receivable after six years, if the rate of discount is 12 per cent.

Table J.2

Future Value Interest Factor for an Annuity

Interest Factor $= \dfrac{[(1 + r)^n - 1]}{r}$

Year Hence	1%	2%	4%	6%	8%	10%	12%	14%	15%	16%	18%	20%
1	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2	2.010	2.020	2.040	2.060	2.080	2.100	2.120	2.140	2.150	2.160	2.180	2.200
3	3.030	3.060	3.122	3.184	3.246	3.310	3.374	3.440	3.473	3.506	3.572	3.640
4	4.030	4.122	4.246	4.375	4.506	4.641	4.779	4.921	4.993	5.066	5.215	5.368
5	5.101	5.204	5.416	5.637	5.867	6.105	6.353	6.610	6.742	6.877	7.154	7.442
6	6.152	6.308	6.633	6.976	7.336	7.716	8.115	8.536	8.754	8.977	9.442	9.930
7	7.214	7.434	7.898	8.394	8.923	9.487	10.089	10.730	11.067	11.414	12.142	12.916
8	8.286	8.583	9.214	9.897	10.637	11.436	12.300	13.233	13.727	14.240	15.327	16.499
9	9.369	9.755	10.583	11.491	12.488	13.579	14.776	16.085	16.786	17.518	19.086	20.799
10	10.462	10.950	12.006	13.181	14.487	15.937	17.549	19.337	20.304	21.321	23.521	25.959

- Calculating the present value using the formula;

$$\text{Rs. } 10\,000/(1 + 0.12)^6 = \text{Rs. } 10\,000/(1.973823)$$
$$= \text{Rs. } 5066.31$$

- Calculating the present value using **Table J.3**:

$$= \text{Rs. } 10\,000 \times \text{Interest factor (from \textbf{Table 10.3})}$$
$$= \text{Rs. } 10\,000(0.507)$$
$$= \text{Rs. } 5070$$

Shorter discounting period.   If the discount is compounded more frequently, say four times a year, then the present value of Rs.10 000, discounted at 12% in six years, can be calculated as follows:

$$FV = PV(1 + r/m)^{m \times n}$$

Where,

   $m = 4 =$ number of times compounding is done in a year.
   $n = 6 =$ number of years compounded

Therefore, in this case

$$PV = \text{Rs. } 10\,000/\{1 + 0.12/4\}4 \times 6$$
$$= \text{Rs. } 10\,000/1.9738232$$

Table J.3

Present Value Discounted Factors for Future Single Payments

Discounted Factor $= \dfrac{1}{(1+r)^n}$

Year Hence	1%	2%	4%	6%	8%	10%	12%	14%	15%	16%	18%	20%
1	0.990	0.980	0.962	0.943	0.926	0.909	0.893	0.877	0.870	0.862	0.847	0.833
2	0.980	0.961	0.925	0.890	0.857	0.826	0.797	0.796	0.756	0.743	0.718	0.694
3	0.971	0.942	0.889	0.840	0.794	0.751	0.712	0.675	0.658	0.641	0.609	0.579
4	0.961	0.924	0.855	0.792	0.735	0.683	0.636	0.592	0.572	0.552	0.516	0.482
5	0.951	0.906	0.822	0.747	0.681	0.621	0.567	0.519	0.497	0.476	0.437	0.402
6	0.942	0.888	0.790	0.705	0.630	0.564	0.507	0.456	0.432	0.410	0.370	0.335
7	0.933	0.871	0.760	0.665	0.583	0.513	0.452	0.400	0.376	0.354	0.314	0.279
8	0.923	0.853	0.731	0.627	0.540	0.467	0.404	0.351	0.327	0.305	0.266	0.233
9	0.914	0.837	0.703	0.592	0.500	0.424	0.361	0.308	0.284	0.263	0.225	0.194
10	0.905	0.820	0.676	0.558	0.463	0.386	0.322	0.270	0.247	0.227	0.191	0.162

❑ J.5   PRESENT VALUE OF AN ANNUITY AMOUNT

An annuity is a series of periodic cash flows of equal amount. It can be payments or receipts.

$$PV_a = A \frac{\left[(1+r)^n - 1\right]}{r(1+r)^n}$$

Where,

PV_a = Present value of amount received in n years

A = Regular annual cash inflow

r = Discount rate per annum

n = Period of annuity

Example: Calculate the present value of Rs. 10 000 received per year regularly at the end of each year for three years when the discounted rate is 10% per annum.

- Calculating the present value using formula:

$$PV_a = A \frac{[(1+r)^n - 1]}{r(1+r)^n} = 10000 \frac{[(1+0.1)^3 - 1]}{0.10[(1+0.1)^3]} = 10000 \frac{(3.31)}{1.331} = Rs. 24788$$

- Calculating the future value using **Table J.4**, the present value annuity interest factor is (2.487).

Therefore,

$$\text{Present value of the annuity} = 10\ 000(2.487) = Rs.\ 24\ 870$$

Table J.4

Present Value Discounted Factors for Annuities

Discounted Factor $= \dfrac{[(1+r)^n - 1]}{r(1+r)^n}$

Year Hence	1%	2%	4%	6%	8%	10%	12%	14%	15%	16%	18%	20%
1	0.990	0.980	0.962	0.943	0.926	0.909	0.893	0.877	0.870	0.862	0.847	0.833
2	1.970	1.942	1.886	1.883	1.783	1.736	1.690	1.647	1.626	1.605	1.566	1.528
3	2.941	2.884	2.775	2.673	2.577	2.487	2.402	2.322	2.283	2.246	2.174	2.106
4	3.902	3.808	3.630	3.465	3.312	3.170	3.037	2.914	2.855	2.798	2.690	2.589
5	4.853	4.713	4.452	4.212	3.993	3.791	3.605	3.433	3.352	3.274	3.127	2.991
6	5.795	5.601	5.242	4.917	4.623	4.355	4.111	3.889	3.784	3.685	3.498	3.326
7	6.728	6.472	6.002	5.582	5.206	4.868	4.564	4.288	4.160	4.039	3.812	3.605
8	7.652	7.325	6.733	6.210	5.747	5.335	4.968	4.639	4.487	4.344	4.078	3.837
9	8.566	8.162	7.435	6.802	6.247	5.759	5.328	4.946	4.772	4.607	4.303	4.031
10	9.471	8.983	8.111	7.360	6.710	6.145	5.650	5.126	5.019	4.833	4.494	4.192

❑ J.6 PRESENT VALUE OF CASH INFLOW OF UNEQUAL AMOUNT AND DISCOUNT

$$NPV = \sum_{t=1}^{t=n} NCF/(1+r)^n - \text{Investment}$$

Example: Calculate the Present Value of a stream of cash flows, the amount and the discount projections of which are given below:

	Year 1	Year 2	Year 3	Year 4
Cash flow		24.87	43.86	45.87	55.05
Discounted rate		12%	10%	10%	10%

Solution: Using the values of discounting factor given in **Table J.3** for one year, two years, three years and four years:

PV (in lakh) = 24.87 × 0.893 +43.86 × 0.826 + 45.87 × 0.751 + 55.05 × 0.683

= 113.05

Planning Construction Costs

Cost as well as financial accounting systems make use of the same revenue and expenditure data (**Figure 11.1**), however, there is a basic difference between them. Cost accounting is an internal accounting system that is designed for managing costs of resources in an organisation. It provides information for controlling costs, whereas, financial accounting involves recording, classifying, summarising, and presentation of the financial status of the past events for the organisation, to stakeholders, legal authorities or financial institutions, who are not directly involved in the day-to-day running of the organisation.

Cost management deals with the management of costs of Project Resources. It covers the effective implementation of cost management processes including estimating, planning, budgeting, monitoring and controlling costs with the objectives of project completion within the approved budgets along with authorised variations. Cost management also covers forecasting of construction costs that are related part of project cash flow. The WBS forms the basis for the budgetary allocations and assignments of control accounts for the cost tracking and control processes.

Generally, it is the corporate management that establishes cost management policies and procedures. It describes how the project performance will be measured and managed. The commonly used formulae for measuring performance using earned value management technique are given in **Chapter 15**. Some experts include funding and managing finances as part of the cost management but being specialised topics, these are not covered in this chapter.

In construction projects, generally, there are two parties, whose investments are involved; these parties are the clients and the contractors. The cost control objectives of the involved parties may differ from each other.

Client investment starts with his decision to go ahead with the project. His expenses continue during design, execution and commissioning stages. After taking into consideration the client's

Figure 11.1

Finance and Cost Accounting Interface

Balance Sheet (1,000)				
Share Capital			(1,000)	
Long Term Loans			200	
Retained Profits			35	
			1,235	
Fixed Assets			740	
Stocks	650			
Debtors	60			
	710			
Creditors	(215)			
Bank Overdrafts	(−)			
Working Capital	495		495	
			1,235	

Debtors

Fixed Assets

Inventory

Work-in-progress

Creditors

Cost Accounting	
Sales	x x x x
Variable Costs	(x x x)
Contribution	x x x
Fixed Costs	(x x)
Profit	x x

Sales Accounts

Project Accounts

Book Accounts

Sales Invoices

Purchase Bills

Payrolls

Other Expenses

Cash

overheads, contract commitments, escalation, and contingencies; client formulates cost budget for the project. He plans his cash flow on the basis of the forecast that has been prepared during the engineering stage. He employs a small group to monitor costs, so as to keep the costs within the client's budgete limits and to meet the cash-flow requirement of the project. Through his limited cost control set-up, which is more like finance control, he keeps a constant vigil on the project activities in order to prevent cost escalations and expansions without purpose. He tries to optimise his budgete costs by various measures, such as economising the scope of work by using value analysis techniques and offering incentives to contractors for early completion, which may yield him early revenue from the project than the originally planned completion time.

On the other hand, it is the contractor, who executes contracted work and bears the cost of input resources, which are employed by him for the work execution. These input resources and site expenses, include the cost of manpower, materials, machinery, and capital. He also incurs expenditure on loan interest, statutory payments, insurance, and so on. In addition, like the client, he has also to control his finances to meet the cash requirements from time to time. His motto is to maximise profits profit margin by effective cost planning, budgeting and control.

Cost planning forms a part of the cost management system. Construction cost planning encompasses planning process, costing techniques, and accounting discipline, for developing standard costs, project budget, and cost control measures, with the ultimate goal of achieving project profit/cost objectives. It uses standard cost concepts for costing work packages, work-items, or activities. The work packages' standard costs facilitate planning, budgeting, and controlling of costs. (Project budget quantifies the project plan in monetary terms and outlines the financial plan for implementation.) Financial forecasts in project budget indicate the trends of expected value of work done, production expenses, and profit and cash flow at specified intervals of time.

This chapter briefly outlines the cost planning methodology. It is divided into the following sections:

1. Methods of Estimating Construction Costs: An Overview
2. Classification of Production Costs
3. Planning Physical Resources Unit Rates
4. Planning Work Packages Standard Production Costs
5. Planning Earned Value of Work Packages
6. Project Time-Phased Baseline Development

The approach for making a Contractor's budget is outlined in **Chapter 12**, and the methodology for Contractor's Costs Controlling including Earned Value Management is covered in **Chapter 15**. The Breakeven Analysis technique is outlined in **Appendix K**. The Clients cost planning, budgeting, and controlling methodology can be developed in a similar manner.

❏ 11.1   METHODS OF ESTIMATING PROJECT COSTS: AN OVERVIEW

11.1.1   Methods of Estimation

Cost estimation is the process of developing approximate monetary resources needed to complete the project work. It is a forecast that is based on the available information. Cost of managing risk is included in the project reserve covered in **Chapter 17**.

There are various methods employed for estimating the project costs. These include clients' unit service cost estimation during conceptualisation phase, parameter estimation based on past performance data during initiation phase, preliminary estimate of work based on Bill of Quantities prior to tendering phase, three point estimate and the contractor's detailed bid estimation at the time of tendering. Cost estimate should be reviewed and updated during the execution phase of the project.

The types of estimates and their nomenclature vary considerably. The methods used depend upon the nature of the project, life cycle phase, purpose for which the estimate is required, degree of accuracy desired, and employed estimation effort. Broad classification of estimates and the estimation methodology as outline is given in **Table 11.1**. However, indicative cost estimate can be taken as the initial rough cost

<div align="center">

Table 11.1

Methods of Estimation

</div>

	Types	Estimation Methodology	Accuracy (Indicative)	Effort Required (Rough as % project cost)
1	Indicative cost estimate	Unit Service Method, Indices Capacity Curves Capacity Ratios	−30 to +40%	0.01 to 0.1
2	Preliminary cost estimate	Parameter cost estimate supported with prevailing Cost Indices, Capacity Curves, Capacity Ratios	−15 to +30%	0.05 to 0.2
3	Approximate cost estimate	Detailed pricing based on quantity take-off from available design and drawings.	−5 to +15%	0.1 to 0.5
4	Definitive cost estimate	Detailed pricing supported with quantity take-off, actual cost incurred and estimated costs for balance work	±5%	1 to 3
5	Detailed bid estimate by a contractor	Detailed pricing at market rate supported with quantity take-off and quotations from potential sub-contractor and suppliers.	±2.5 %	0.1 to 1.0

11.1.2   Client Indicative Cost Estimate

This estimation is initially based on the prevailing unit cost of the facility or service. Examples of cost estimation unit are given below:

Name of Project	Method of Estimation
Building works	Cost per M2 of plinth or floor area
School building	Cost per student
Hospital	Cost per bed
Motels	Cost per visitor or guest
Theatre	Cost per seat
Water storage reservoirs	Cost per litre
Parking areas	Cost per space
Roads, highways and airports	Cost per M2 of surface area
Processing industries	Company Curves, Capacity Ratios

The indicative estimation method needs little time and effort to compute the cost, in case the past performance data and prevailing trend/market rates are available. The range of accuracy of indicative methods varies roughly between ±30% and 40% and, therefore, it has to be further refined by using other estimation techniques, when the architectural and structural drawings and other related information, such as contracted amount becomes available. The prevailing cost depends upon many factors, such as the location, specifications, resources availability, working conditions, and the political environment. The breakdown of the project cost may include the following:

- Land Procurement Cost;
- Preliminary expenses for approval of projects from appropriate authorities;
- Legal expenses;
- Finance engineering expenses;
- Corporate office overhead;
- Project office expenses;
- Cost of construction;
- Engineering and Architect's expenses; and
- Contingencies.

The judgement of client or the promoter, based on the indicative cost estimates that are prepared during the feasibility stage accepts the indicative costs and signals the start of the engineering phase of the project, if the project is feasible and financially viable.

11.1.3   Client's Preliminary Cost Estimate

During the planning and tendering phase, client's technical team or the consultants develop the design, specifications, and drawings, which lead to formulation of preliminary costs and Bill of Quantities (BOQ). Alternately, preliminary costs can also be derived using either the factor estimate or parameter estimate methodology, in case sufficient past performance data is available.

This preliminary costs estimate becomes the basis for initial budgeting costs in order to complete the project. At this stage, the client may review the cost commitments, prior to giving the go-ahead for the tendering action. However, acceptance of the contractor's quoted tender by the client implies his commitment for the payment of the quoted costs.

11.1.4   Client Approximate Project Cost Estimate

Approximate cost estimates are prepared based on detailed designs. The trade-wise BOQ is prepared based on detailed drawings that follows the standard methods of measurements of the involved work items .The Bill of Quantities, also called as the Statement of Costs, provides basis for estimating the approximate costs.

The approximate costs are prepared during the engineering stage by the designers and the estimators. These cost estimates have the accuracy range of –5% to +15% and the time taken depends on the nature and scope of the project, availability of the past performance data, and the method of execution.

The approximate cost estimate forms the baseline for sanctioning budgeted costs, controlling costs, mobilising funds, managing cash flow, and allocating resources.

11.1.5   Clients' Definitive Estimate

The client estimation process is even continued during the execution stage. The client's cost accountant or quantity surveyor, which is based on information from the construction site and other cost centres, undertakes the accounting commitment that include accounting of actual costs, analysing variances from estimated costs, and indicating the cost trends. The progress estimator (of the client) is responsible for the interim payments; estimates the contractor's payments that is based on prices quoted in the BOQ, and thus implies a commitment for the payment to the contractor.

Definitive estimate is prepared when the projects are 70% – 80% complete, which is near completion estimate. It includes the detailed estimate of work quantities including change orders and anticipated final bills of the contractors and suppliers. However, it excludes disputed items and claims.

Finally, on completion, the final bill prepared by the contractor undergoes a scrutiny by the client, where this scrutinised bill gives the final estimate of project costs that is to be incurred by the client.

11.1.6 Contractor's Bid Estimate

On receipt of work tenders from the client's, the contractor prepares his detailed cost estimates for accomplishing the contract stipulation. He quotes his estimated price for the work, which is itemised in the BOQ, and this tendered cost becomes his financial commitment for executing the work, if his tender is accepted by the client. The quoting of tender is a specialised field. Generally, the steps involved in preparation of a tender by the contractor are as follows:

- Compile the estimating data needed for preparation of BOQ;
- Review project scope of work;
- Develop contract WBS;
- Prepare outline plan of work;
- Determine/verify quantities of work;
- Estimate resources unit cost rates (detailed in Section 11.3);
- Calculate the project direct cost of each BOQ item;
- Determine indirect costs share of each work item;
- Add contingencies margin;
- Forecast interest on investments;
- Add Profit margin; and
- Decide on the tender price.

Tendering requires detailed estimation as inaccuracies, both on the plus as well as the minus sides, which can adversely affect the project feasibility and contractor's business respectively. Preparation of detailed estimation is a time consuming process and its accuracy depends on the available time and resources for preparing project estimation. Based on the quantities and costs that are reflected in the BOQ of the tender, the contractor's project planner draws up his plan of work. This plan forecasts the contractor's commitment for resources deployment and input costs and, consequently, the revenue that can be expected from the value of work done (earned value).

Despite, the well-established methodology for project estimation, the glamour of hefty profits and the security of the everlasting market, construction's contracting business still remains a risky proposition. Unlike other industries, where the sale price of the product is determined after its manufacture in construction, generally, the works are priced before they are produced. This estimation of costs before the completion of the project adds up to the business risk of the client as well as that of the contractors. A construction contractor always gambles when he bids for a fixed price contract. A bid on the higher side (of what he considers reasonable) may mean an opportunity missed for new business, whereas, a quotation on the lower side may imply less profits, or possibly a loss or, in rare cases, even the contractor's bankruptcy. When the contractor wins a bid for quoting the lowest, his fellow bidders may question his judgment. Studies reveal that the failure rate of the construction contractors is one of the highest among the various types of businesses. A construction project based on inaccurate cost estimates is bound to fail, unless its performance objectives are revised and/or additional funds inducted.

❑ 11.2 CLASSIFICATION OF PRODUCTION COSTS

The cost of a work-unit, which may be an activity, a work-item or a work-package, is composed of one or more cost elements. These cost elements include labour costs, material costs, plant and machinery costs, administration costs, and other expenses. The process of cost estimation (termed as costing) would be simple if it was possible to directly correlate various cost elements to the activity that incurs them. These costs can then provide a clear picture of the construction costs and thus, helps in simplify planning, forecasting, accounting, and controlling costs. But it is not always possible, to precisely define various cost elements activity-wise. In order to identify the costs associated with an activity, construction costs are generally referred to as production costs, which are categorised into 'Direct costs' and 'Indirect costs' or 'Overheads'.

$$\text{Production cost} = \text{Direct cost} + \text{Indirect cost}$$

Direct costs are costs that can be correlated to a specific activity or a work-item, which is being done or produced. All other costs that are incurred to accomplish the activity or the work-item but cannot be correlated directly fall in the category of indirect costs. The breakdown of the construction cost elements and their inter-relationship, is shown in **Figure 11.2**. These costs are built up as follows:

Production costs are initially estimated for each item of work as stated in the project work scope. These are listed under BOQ and can be combined or split up to determine the cost of each work-package, using the technique described earlier in **Section 3.3.5.**

11.2.1 Direct Resources Costs

These are costs of materials, labour, and other expenses, which can be identified with the execution of an item of work or activity.

$$\text{Direct cost of permanent work item} = \text{Direct materials cost} + \text{Direct labour cost} + \text{Other direct expenses}$$

Direct materials cost. These cover all costs that are connected with materials, which are incorporated into permanent works of the project. These can be measured and costing done item-wise. For example, materials used in concrete work of a specified concrete mix can be measured and its allocated cost to the concreting activity in terms of costs of cement, sand, aggregate, admixture and water, per cubic meter of ready-mix concrete. The direct materials cost at construction site, generally, includes the following:

- Purchase costs, ex-factory or specified delivery location;
- Transportation costs, including freight by rail, road, ocean, custom clearance, insurance and handling charges till arrival at site, as applicable; and

Figure 11.2

Construction Costs Breakdown

Direct Costs Breakdown		Indirect Costs Breakdown		Total Costs Breakdown
Direct Materials Cost	+	Indirect Materials Cost	=	Materials Costs
+		+		+
Direct Labour Cost	+	Indirect Labour Cost	=	Labour Cost
+		+		+
Direct Expenses'	+	Indirect other Expenses	=	Other Expenses
=		=		=
Direct Costs	+	Indirect Costs	=	Total Costs
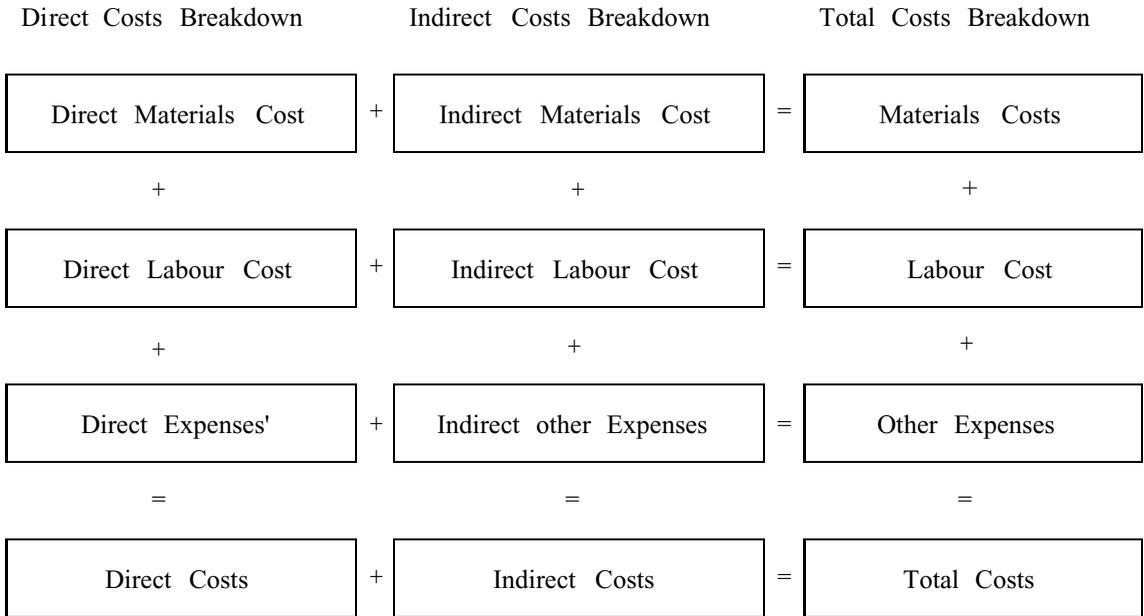
	Cost Elements	**Amount**
(i)	Direct material costs	A
(ii)	Direct labour costs	B
(iii)	Direct other expenses	C
(iv)	Direct Costs (A + B + C)	D
(v)	Indirect Costs	E
(vi)	Total Production Costs (D + E)	F

- Site manufacturing and fabrication costs to transform raw materials into products for use in permanent works;
- Examples of such items are doors and windows fabrication, steel reinforcement fabrication, cement tiles and manufacturing hollow blocks;
- In order to make a comparison with the rates of these materials prevalent in local markets; moreover, their site's overheads can also be included into direct manufacturing and fabricating costs.

It is not necessary to have detailed costing of all types of materials that go into the production of an item of work or activity. Minor material items like screws, nails, and trade men's tools can best be grouped under one head titled 'minor materials and tools' in the indirect material costs.

Direct labour costs.   It covers net expenses for procurement, maintenance, and wages of all category of workers, who are employed at the work site for the execution of project item. These expenses include:

- Basic wages;
- Overtime and allowances;
- Procurement expenses including recruitment and conveyance at site;
- Benefits and statutory regulation compensation expenses such as earned leave, provident funds, gratuity, bonus, insurance, medical, etc.; and
- It also covers expenditure on accommodation and mess amenities if these are not covered under overheads.

Another method for evaluating direct labour cost is to cover only salary and wages under direct cost and consider the balance expenses under indirect labour costs.

Other direct expenses.   These include all other expenses on account of services rendered, which can be directly attributed to and clearly identified with the execution of an activity or work-item. Examples of such expenses are:

- Special purpose plant and machinery costs, such as owning and operating costs of concrete production, transportation, and placing equipment;
- Sub-contracted activities;
- Hired resources costs for execution of specified permanent work, like excavator for trenches;
- Temporary activity required for a specific work like erecting a scaffolding platform for plaster work;
- Special technical consultant services, such as architecture, designing, investigation, etc. when these are proportioned as indirect cost of activities; and
- Investigation/trials necessary to establish procedures for undertaking the construction of a given work or activity, such as making concrete circular wall for a water treatment plant, or driving of foundation piles.

11.2.2   Indirect Costs

Indirect costs include costs, which are attributable to a given project but cannot be identified with the performance of a specific activity or a work-package. In other words, all costs other than direct costs are covered under indirect costs.

In construction projects, indirect costs or overheads constitute to a significant amount. The range of indirect costs, depending upon the nature of the project, may vary from 7.5% to 35% of the total costs. To quote an example, the indirect costs of a typical small-size building construction project are outlined in **Table 11.2**.

The indirect costs cover a wide range of items. To quote an illustration, the items grouped under indirect costs of a multinational construction company are listed in **Exhibit 11.1**. The items of indirect costs depend upon the type and size of the project. A typical breakdown of these costs grouped on a functional basis is shown in **Exhibit 11.2**.

Table 11.2

Indirect costs of a typical small-size building construction project

S. No.	Types of Indirect Costs (Other than Direct Costs)	Percentage Mark up of Direct Cost
1.	Project supervisor and other indirect labour including management costs	5%
2.	Project office expenses	3%
3.	Design and drawing costs	2%
4.	General purpose plant and machinery cost	3%
5.	Finance, risk management and contingencies	4%
6.	Accommodation, utility services and furnishing	4%
7.	Tools and minor equipment	2%
8.	Home office overheads and public liabilities	3%
		26%

In general, from a performance consideration, indirect costs can be broadly divided as follows:

1. **Production overheads.** These include all indirect manpower, indirect materials and other indirect expenses incurred by each production responsibility centre.

	Nature of costs	*Examples*
(1)	Indirect manpower costs	Salary and wages of supervisors and other indirect workers.
(2)	Indirect material costs	Tradesmen's tools, minor equipments and consumable materials.
(3)	Indirect other expenses	General purpose plant hiring costs.

Exhibit 11.1

Typical Indirect Costs Classification of a Multinational Construction Company

1. *Supervisor:* It includes construction management and related staff.
2. *Indirect personnel:* It includes logistics, clerks, security, site cleaning, warehousing, maintenance of equipment, (except personnel involved in temporary facilities construction, operation, maintenance and dismantling).
3. *Temporary site facilities:* It includes supply, installation (Including labour) and dismantling of temporary facilities such as, but not limited to;
   - Furnished offices to be installed at the job site.
   - Fencing of equipment, warehouse and storage areas.
   - Shops for fabrication or maintenance purposes.
   - Installation of temporary utility services network (electrical, industrial water potable water sewer, telecommunication and air).
   - Sanitary facilities.
   - First aid facilities.
   - Construction of temporary roads, fences, car parks. Necessary storage facilities for fuel, water.
   - Safety materials.
4. *General field expenses:* It consists of operating costs associated with temporary facilities such as but not limited to;
   - Supply of stationary, documentation, photography, cleaning products, pharmaceutical products.
   - Communication (Phone, telex, postage).
   - Utilities consumption.
   - Administrative permits, medical checks.
   - Other field office expenses.
5. *Equipment costs:* It covers costs associated (except transportation cost) with constructional equipment, vehicles, cars, spare parts, in the entire duration of project.
6. *Small tools* and *consumables:* It includes costs of fuel, lubricants, small tools, wearing parts and consumables.
7. *Housing costs:* It covers supply, installation and dismantling of camp and related facilities (kitchen, temporary roads, utility materials.)
8. *Catering costs:* It includes catering laundering and camp operating costs.
9. *Mobilisation and demobilisation:* It caters for personnel equipment, temporary facility item, small tools, consumables, camp structure and other facilities.
10. *Other facilities and Overhead*:

Exhibit 11.2

Indirect Costs: Functional Breakdown (Where not Covered Under Cirect Costs)

1. *Client consultant requirements:*   Manpower, accommodation, furniture and fittings, telephone, stationery, equipment, operating and maintenance, survey equipment, photography, transport, incidental expenses.
2. *Head office expenses:*   Connected with project work-planning and co-ordinating, consultancy services, visits, entertainments, bank guarantees, bank service charges, taxes and incidental expenses.
3. *Project office expenses:*   Accommodation, furniturve and fittings, telephone, stationery, equipment, operation and maintenance.
4. *Establishments expenses:*   Field supervisors, technical staff and workers, materials management staff and workers, plant and machinery management staff and workers, administration staff, workers and managers.
5. *Personnel management costs:*   Mobilisation and demobilisation, stationery expenses, medical, messing, camp maintenance, personnel carriers, security, amenities and welfare, entertainment, insurances, incidental and protective clothing.
6. *Technical management costs:*   Designs and drawings, project consultancy, data processing, site laboratory and testing, technical library, sub-contracted workers expenses, site surveying, incentive scheme, tie crashing, formwork, drawing office equipment, after completion maintenance, site clearance.
7. *Materials management costs:*   Inventory holding costs, site materials handling costs, tradesmen tools and minor equipment costs, minor materials costs, losses/wastages costs, load carriers expenses, demurrages/breakages, insurance and demobilisation.
8. *Plant and machinery management:*   (deduct for costs catered elsewhere)-Mobilisation costs, owning costs, operating costs, fuel/oil/lubricant costs, repairs costs, spare inventory costs, operators and drivers costs, statutory expenses, personnel carriers expenses and demobilisation.
9. *Finance and risk management costs:*   Bid bond, performance bond, work insurance, social security, contribution, unforeseen fines and penalties, escalation, bank service charges, bank guarantees, local taxes.

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2.   **External support services costs.** These cover all indirect manpower, materials, and other expenses of the functional set-ups that are been concerned with providing technical and logistic support to the production centres. Examples are as follows:

- Technical design and quality control -services;

- Materials-on-site manufacturing services;
- Equipment supply services;
- Personnel and security services; and
- General services including temporary works and camp utility services.

3. **Administration overheads.** These contain indirect manpower, materials, and other expenses that are been incurred by the project management for the direction, control, and administration of the project. The costs covered under this head include:

- Office management costs;
- Planning and coordination management costs;
- Technical management costs;
- Marketing, costing, and contract management costs;
- Resources management costs; and
- Finance and risk management costs.

4. **Home office overheads.** These overheads represent the expenses relating to the operations and services that are rendered by the home-office. These costs include the consultant's fee, legal expenses, licensing charges, visits, entertainment taxes, insurances, and a share of the home-office running expenses. Home-office overheads are specified by the corporate management.

The above functional grouping and its breakdown are not rigid. These are guidelines and can be suitably modified in line with corporate policy and project characteristics.

11.2.3 Indirect Costs Behaviour

An estimator, at the time of costing, computes all the indirect costs in detail or evaluates by using predetermined company norms. The estimator apportioned these indirect costs to the direct costs for calculating the final production cost. But, this is not adequate for planning, budgeting, and controlling costs. In order to analyse the cost behaviour, either a planner or the cost accountant, further splits up each item of indirect cost into two to three broad categories, such as variable costs, fixed costs, and semi-variable costs.

1. Variable costs tend to vary directly with the volume of production, i.e. work done or output. No production means no cost. Cost rises as the volume of production increases. These costs change at a constant rate (assumed) to change in the volume of production, as shown below:

Nature of Variable Indirect Costs
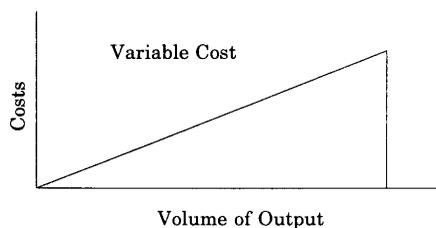
Examples of indirect variable costs are telephone operating expenses, camp messing expenses, and office stationery expenses

2. Fixed costs do not show any appreciable fluctuations with change in production levels. These costs are either one-time cost, like the camp construction cost; periodic costs, such as supervisor's salary; or are monthly recurring expenses like monthly rent for project office and monthly depreciation for project construction equipment.

Nature of Fixed Indirect Costs
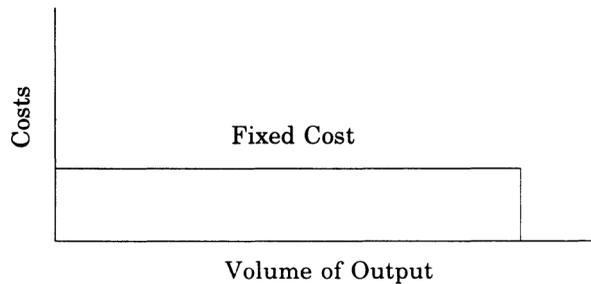
3. Semi-variable costs are partly fixed and partly variable in nature. Examples of these are, telephone expenses, which consist of fixed installation expenses, and variable operating expenses, which vary with the volume of work or production activities:

Nature of Semi-variable Indirect Costs
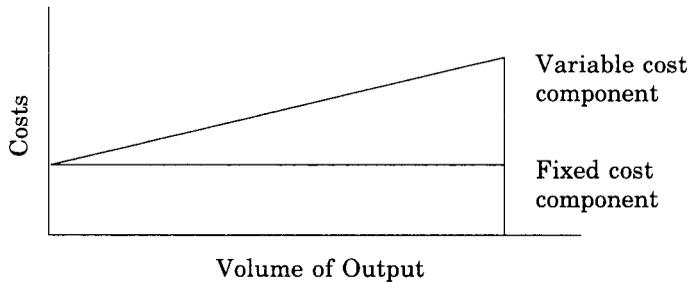
It is not always feasible to clearly demarcate the indirect costs into variable and fixed categories, as many cost behaviour patterns are possible. But for apportioning indirect costs, it is necessary to divide each item of indirect cost broadly into production-related variable indirect costs and periodic or time-related fixed indirect costs.

The methodology for sharing of Indirect Cost is covered in **Section 11.4**.

❑ 11.3 PLANNING RESOURCES UNIT RATE

11.3.1 Costing Approach

Physical resources include the manpower, equipment, materials, subcontractor, and services, which are utilised in order to complete the work. The identification and unit rate costing of the resources, their needed quantity, and the scheduled requirement of these resources are directly linked to the expected cost of the project work. The net resources cost are either in unit of time or measure, such as cost per hour, cost per metric ton, or cost per use. Generally for each activity, the cost of resources of manpower, equipment, and materials are categorised and computed in terms of hourly cost as under:

Activity labour cost = Labour effort in man-hours × Standard labor hourly rate

Activity equipment utilisation cost = Equipment utilisation hour × Standard equipment hourly rate

Activity materials cost = Materials consumption quantity × Standard materials unit price

Methodology for determining labour productivity standards, equipment output standards, and materials consumption standards are covered in Chapters 7–10. The technique for developing a standard labor hourly rate, equipment hourly rate, and materials unit price is covered in subsequent paragraphs.

11.3.2 Labour Standard Hourly Rate

Direct labour, which is employed on monthly or daily wages, is paid on an hourly rate basis. Complete labour hourly standard rate includes, net expenses incurred on procurement, wages, benefits, and statutory costs. The labour hourly standard rate is determined for each category of direct labour, employed at the site of production work. For costing purposes, direct labour is categorised into foremen/supervisors, highly skilled, skilled, semi-skilled and unskilled. In some firms, semi-skilled and unskilled are treated at par, and both are grouped into the category of general helpers. The method of calculation of labour hourly standard rate involves the determination of annual labour estimated cost and the number of productive hours worked in the year.

$$\text{Labour hourly standard cost } = \frac{\text{Annual estimated labour cost}}{\text{Annual productive hours}}$$

To quote an example, consider the case of an Indian expatriate skilled worker employed in Saudi Arabia in the year 1990 on a monthly wage of Saudi Riyal (SR) 750 who is being provided free accommodation, food, and medical aid. This worker is employed on two years' contract; he gets leave at the rate of 15 days per year after the completion of his contract and his gratuity and other

entitlements are governed by the Saudi Labour Law. The hourly standard rate for this worker can be calculated as follows:

a. Estimating annual productive hour:

	Calendar days in a year	=	365
Less:	Weekly holidays on Friday at the rate of one per week	=	52
:	Public holidays as per Saudi Labour Law excluding Friday		10
:	Reduced working time during Ramadan month at 2 hours per day for 24 days (assessed)	=	6

$$\text{i.e.} \quad \frac{2\text{hours}}{8\text{hours}} \times 24\text{days} \qquad C = \frac{A}{Q}$$

:	Unproductive time during bad weather (assumed)	=	17
:	Casual leave/sickness (assumed)	=	10
Net working days in a year			270 days

Therefore, annual productive working hours at 8 hours per working day (8 × 270)   =   2160 hours

b. Estimating total annual expenses:

A.	Annual wage at SR 750 for 12 months	=	9000
B.	50% of recruitment expenses at SR 500 for two years (0.5 × 500)	=	250
C.	Airfare one way (first year mobilisation and second year demobilisation on completion of contract)	=	1,250
D.	Messing at SR 300 per month	=	3,600
E.	Medical (assessed from past statistics)	=	450
F.	Accommodation at SR 100 per month	=	1,200
G.	Annual leave equivalent 1/2 month's wage	=	375
H.	Gratuity equivalent 1/2 month's wage	=	375
I.	Insurance and social security contribution	=	600
J.	Other expenses like sports, entertainment, etc.	=	1,200
	Total expenses		18,300

Therefore, labour hourly standard rate

$$= \frac{\text{Annual estimate cost}}{\text{Annual productive hours}}$$

$$= \frac{\text{SR } 18,300}{2160 \text{ hours}}$$

$$= \text{SR } 8.45 \text{ per hour; say SR } 8.50 \text{ per hour}$$

Proceeding similarly, the hourly labor rate of various categories can be computed easily by using an hourly labor rate as shown in **Table 11.3**.
vvThe labour rates can be expressed in different forms as under:

A = Hourly labour rate of a crew
B = Average hourly labour rate per worker of a crew

$$\text{B} = \frac{\text{A}}{\text{N}} \quad \text{and} \quad C = \frac{A}{Q}$$

Where,

A = Hourly labour rate of the crew
N = Number of workers of the crew
C = Crew cost per unit of work
Q = Quantity of work done in one hour.

For example, if a crew consisting of two carpenters and one helper can fix 10 square meters of slab form work in 8 hours, and the labour hourly rate of a carpenter is SR 8.50 and a helper is SR 6.95, then

A = Hourly labour rate of the crew
   = 2 × 8.50 + 1 × 6.95
   = SR 23.95.

B = Average hourly rate per worker of the crew

$$= \frac{A}{N}$$

$$= \frac{23.95}{3}$$

= SR 7.98

Table 11.3

Hourly Labour Rate Calculation Sheet

Serial Code	Cost Head	Personnel Category Annual Expenditure in Saudi Riyals			
		Foreman	Highly Skilled	Skilled	Unskilled
A	Annual wages	18,000	12,000	9,000	6,000
B	Recruitment expenses at SR 500 for two years employment contract.	250	250	250	250
C	Airfare one way (first year mobilisation and second year de-mobilisation)	1,250	1,250	1,250	1,250
D	Messing at SR 300 per month for 12 months	3,600	3,600	3,600	3,600
E	Medical assessed from past statistics	450	450	450	450
F	Accommodation at site	2,400	1,200	1,200	1,200
G	Annual leave equivalent half month wages	750	500	375	250
H	Severance pay equivalent half month wages	750	500	375	250
I	Insurance and social security	750	600	600	600
J	Other expenses such as sports, entertainment, incentive etc.	1,500	1,200	1,200	1,200
K	Total Annual Expenses (Sum of A to J)	29,700	21,550	18,300	15,050
L	Annual Productive Hours	2,160	2,160	2,160	2,160
M	Labour hour (K ÷ L)	13.75	9.98	8.47	6.97
	Standard rate (say)	13.75	10.00	8.50	7.00

$$C = \text{Crew cost per unit of work} = \frac{\text{Labour rate per hour}}{\text{Output quantity per hour}}$$

$$= \frac{23.95}{10/8}$$

$$= \text{SR } 19.16/\text{m}^2 \text{ of form-work}$$

It may be noted that various cost heads that are been listed in **Table 11.2**, provide a simplified approach. These cost heads and their corresponding basis for computing annual expenditure vary with the company accounting system and the prevalent statutory regulations at the project site. In some cases, where provisions are made for expenditures like overtime, tool cost, bonus, pension, insurance and taxes, the calculation of hourly labour rate becomes a difficult process. Further, it is not necessary to take into account all expenses, while calculating direct labour hourly rate. Some companies, who employ labour supplied through sub-contractors, have predetermined hourly labour rates. Some other companies consider monthly salary and wages only under labour direct hourly rate and account expenditure like mobilisation and housing and statutory benefits under indirect labour costs.

11.3.3 Equipment Hourly Standard Rate

The method of estimation of the equipment hourly rate is covered in Section 10.2.3.In brief, this involves the estimation of equipment owning and operation costs:

Equipment rate per hour	=	Owning cost per hour + operating cost per hour.
Where, Owning cost	=	Depreciation + Interest on investments +taxes
and Operating cost	=	Fuel cost + Maintenance cost + Major repair cost + Operator's cost + Tyre replacement cost for rubber tyred equipment.

The approach of the above equation for determining the equipment hourly standard rate can best be treated as a guideline, because of availability of factors, determinate as well as indeterminate, which affect the equipment owning and operating costs. These factors include the state of the equipment (old or new), corporate capitalisation policy, sources of funding for the new purchase, site delivered price, purchase implication on corporate taxes, economical plant life in years, resale value, annual operational hours contemplated, past performance record (in the case of old equipment), job conditions, skill of the operator, and the repair and maintenance facilities available. Equipment utilisation rate also depends upon its ownership. This rate will be different if it is taken from the client's own plant rather than if it is rented from the market. There is no substitute to the experience of the estimator. Therefore, while establishing hourly standards for an item of equipment, the mathematically estimated equipment utilisation rate is suitably modified by the experienced estimator according to the situation.

11.3.4   Materials Standard Price

Materials standard price is defined as the estimated all-in price of the unit quantity of an item, which is delivered at the project site. This all-in price includes source price, wastage costs, transportation costs up to site, and taxes involved. Site storage and handling costs from site warehouse to construction sites can be covered under indirect costs.

The purchase price of each item can be ascertained by inviting quotations and then concluding a supply sub-contract with the selected supplier. Some items can be priced from standard price catalogues, commercial cost guides, and past experience. Although, enquiries regarding the purchase price are made by the estimator at the tender stage, the prices may vary from time to time. The purchase price depends upon many considerations, such as quantity required, lot-size of each delivery, delivery dates, specifications, shelf-life and payment terms. The true picture of the purchase price can only be known after the quotations are received for each item, which is time consuming and not feasible, especially, when the standards are to be set at the stage of project planning. Therefore, direct materials standard price can best be estimated by the project materials manager, who in due course is required to control these prices. However, the following needs to be noted:

1. The materials standard price can be fixed and does not change with market fluctuations. These fixed price standards simplify the estimation, planning, budgeting, and control of material costs. The variance between the standard price and the actual price is analysed at the time of accounting costs.
2. It is not necessary to evaluate the standard price of each item. The standard price should be established majorly for high value A and B categories of materials. The ABC materials classification system is covered in **Chapter 8**.
3. Consumable materials like screws, nails, tools, etc. need not be individually priced. These can best be grouped under a separate accounting head of indirect materials and charged at a predetermined percentage of labour cost, direct material cost, prime cost, or direct cost.
4. In case of fixing the standard price for site manufactured or site fabricated materials like ready-mix concrete, fabricated steel enforcement, manufactured doors and windows, precast masonry blocks, and other concrete elements, the standard price should also include site overheads, so that the end product's price can be compared with the prevailing marketing prices. To quote an example, the pricing methodology for establishing the standard price for the site manufactured ready-mix concrete at break-even is described in the next section.

11.3.5   Service Supply Cost

The method of determining prices of rendered services will depend upon the nature of service, which is been rendered. For example, the service centre like a 'materials transporting centre will have to go into service costing in order to calculate the charges per km of the product transported,

and the 'equipment supplying centre' will need to cost the owning and operating costs to determine the hiring charges.

The price of site manufactured materials can be determined by computing the break-even point (BEP). The BEP marks the lowest level at which the production cost and sale value of deliveries are equal, resulting in a no profit-no loss situation, which is the point at which the fixed costs are totally absorbed. The break-even methodology is described in **Section 11.7**.

❏ 11.4 PLANNING WORK-PACKAGE STANDARD PRODUCTION COST

A work-package comprises of some activities. Each work-package contains identifiable, quantifiable, measurable, and cost-able packages of work. In the process of plan development, each work package is assigned its performance objectives that are generally stated in terms of its completion period, standard cost, and standard sale (contracted) price. The primary purpose of standardising work package cost is to:

- Freeze the expected production cost under operating conditions with normal facilities;
- Account the costs being incurred during the execution stage;
- Compare the actual cost with the budgeted cost for corrective action; and
- Forecast the future costs.

Further, wherever feasible, the standard costs should be developed jointly by the estimating, planning, financing, and resources accounting staff, all working under the directions of the project manager. Ultimately, it is the project manager who has to accept and live with these standards. The concept behind standardising costs, the method of determining the work-package standard cost, and the standard sale price are outlined in subsequent paragraphs.

11.4.1 Standard Cost Concept

The standard cost of a work-package, a work-item, or an activity represents its pre-determined production cost objective. While, the term cost relates to the production cost, the concept of 'standard' varies with the purpose for which that standard is established. The commonly used cost standards encountered in the construction industry are:

a. *Basic cost standards (or norms):* These are production cost standards that are been developed by a firm using its past experiences with all-in costs being priced at prevailing rates. Some of the government construction agencies and established contracting firms publish their basic cost standards in the form of 'Standard schedule of rates'.

b. *Currently attainable standards:* These are standards developed by updating basic cost standards so as to convert the basic production costs into currently attainable production costs standard.

c. *Ideal cost standards:* These represent the estimated production costs for an activity, work-package or work-item assuming, the most efficient use of present or planned resources and facilities.

d. *Normal cost standards:* These standards reflect the general production costs valid for longer periods of time as compared to short-period costs that are defined by currently attainable standards.

Standard costs, on the other hand, stand for the expected average production cost of a work-package, activity or work-item of a specific project, assessed at the project planning stage, which adopts a planned method of execution of work, using planned resources and allowing normal delays and wastage while operating efficiently under the prevailing working conditions. These become the cost objectives. It may be noted that the standard costing methodology is similar to the method of estimation of cost at the pre-contract stage. The main difference is that the tendered costs are estimated at the pre-contract stage by the estimator and the standard costs are established by the project management, after the contract is been awarded, by reviewing the earlier tendered costs, as it is based on the production method proposed to be adopted and not on the pre-contract stage assumed production method.

11.4.2 Standard Costing Methodology

The production cost of a work-package in a standard work-unit can be estimated using the following relationships:

Production cost	=	Direct equipment expenses
Where,		
Direct cost	=	Direct labour cost + Direct material cost + Direct equipment utilisation cost + Other direct expenses
Direct labour cost	=	Work quantity × Workers' productivity standard ×Labour standard hourly rate
Direct materials cost	=	Work quantity ×Material consumption standard × Material standard unit price
Direct equipment expense	=	Work quantity ×Equipment output-standard × Equipment standard hourly employment costs
Direct other expenses	=	Remaining direct expenses not covered above
Indirect cost	=	Apportioned variable overheads + Apportioned fixed overheads

The expected average production cost of a work-package under operating conditions with facilities functioning normally is termed as the standard cost. The standard cost of production of a work-package can preferably be determined in terms of its 'Work-unit', i.e. m^3 is taken as a work-unit for costing concreting activity. These work-units are the standards used for measurement as specified in standards like 'Indian Standard IS 1200 (Parts 1–28) on Methods of Measurement of Building and Civil Engineering Works'.

11.4.3   Estimating Standard Direct Cost

The estimation of the standard direct cost for a work-package, thus involves:

- Estimation of the quantity of work that is to be executed in standard units of measurement;
- Setting up of the workers' productivity standard, materials consumption standard, and equipment utilisation standard (These are described in **Chapters 7–10**); and
- Developing costing standards for labour hourly rate, material's unit price, equipment utilization hourly rate, and evolving methodology for apportioning indirect costs and evaluating standard costs. (These unit-rate costing standards for direct resource estimation are covered above).

To quote an example, consider the case of the 'foundation task' of a housing unit project.

The labour costs and materials costs are derived for each work-package from the data reflected in **Chapter 3**, and these are tabulated in **Table 11.4**.

11.4.4   Sharing of Indirect Costs

The indirect costs are detailed at the time of estimating project costs. The estimators use various methods for absorbing these indirect costs into production costs. These costs can be charged (or added) to the direct costs on a proportionate basis. In some contracts, most of the indirect costs are priced under the preliminaries section of the bill of quantities and the balance is distributed proportionately in the remaining items of the BOQ.

Another method sharing indirect costs is to divide the indirect costs under four heads, i.e. indirect manpower costs, indirect materials costs, indirect equipment costs, and indirect other expenses, then distributing these costs to the production direct costs using predetermined criteria. But the sharing of indirect cost for use in planning, budgeting, and controlling, is a complex process as it involves knowing what the costs are, who has incurred the costs, what the nature of the costs was, and how to share these indirect costs, for evaluating work-package standard costs.

What are the indirect costs involved?   The indirect costs that are considered include those costs which cannot be identified with the execution of the work-packages pertaining to permanent works. The types of indirect costs encountered in a typical project are shown in **Exhibits 11.1** and

Table 11.4

2000 Housing Units Project Standard Direct Cost in Dollars of One Foundation Module (Actual Data Modified)

S. No.	Work Package Description	Manpower Cost	Material Cost	Other Cost	Total Direct Cost
1.	Base Preparation	613	2178	463	3254
2.	Raft	820	13732	1701	16254
3.	Plinth Wall	1637	5079	1163	7880
4.	Ground Floor	363	3817	527	4705
	Total Direct Cost per Module	3433	24806	3854	32093

11.2. The amount of expenses involved requires a detailed computation of the indirect costs, costing each item one by one, and then aggregating them to determine the total indirect cost.

Who incurs these costs?   Indirect costs are incurred by various functional groups of the project employed to produce work, support production, or administer production. These functional groups are called 'Responsibility or Cost Centres. Project responsibility centres, depending upon the task assigned can be broadly divided into four categories:

- Production or profit responsibility centre;
- Support services responsibility centre;
- Administration responsibility centre;
- Sales and contract administration centre; and

The methodology for structuring cost centres is outlined in **Chapters 8** and **12**.

What is the nature of indirect costs?   Each item of indirect cost from the production point of view can be divided into two broad categories, i.e. variable overheads and fixed overheads. These can be grouped separately for each responsibility centre:

Responsibility centre	Variable overheads	Fixed overheads
Production centre	xx	xx
Service centre	xx	xx
Administration centre	xx	xx
Sales and contract centre	-	xx
Project cost	xxx	xxx

How to share indirect costs? Since production centres produce permanent works, which are grouped into work-packages, all overheads, are finally charged to work-packages, by allocating them a predetermined part of all indirect costs (variable and fixed). The sharing process aims at the allocation of indirect costs to the work-packages, using a fair distribution policy so as to derive the work-package standard cost.

Work-package standard cost = Work-package standard direct Cost
          + Shared variable overheads
          + Shared fixed overheads.

There is no tailor-made solution for sharing of indirect costs. The sharing methods vary from company to company and project to project. Generally, the method of sharing involves apportionment and absorption of indirect costs. Cost apportionment refers to the process of allocating project overheads among various responsibility centres, whereas overhead absorption stands for the process of allocating the production centre's overheads within its work-packages. The sharing process can be divided into the following sequential stages:

1. **Apportioning administrative overheads to production centre.** Apportion administration variable overhead costs to various production centres by using a fair distribution method. To quote an example, some typical costs considered under this head and their basis of distribution is as follows:

Administration variable overheads	*Basis of cost distribution*
Accommodation rent	Floor area occupied by rsponsibility centres.
Building maintenance	Percentage of rent
Office running expenses	Manpower costs of each centre
Depreciation	Book value of equipment.

   Another method of apportionment for administrative variable overhead costs is to distribute these to responsibility centres in proportion to the value of work that is entrusted or in pro-rata percentage of their manpower costs or any other suitable criteria.

2. **Apportion service centre costs to production centres.** All service responsibility centres' costs, including the allocation of administration centre costs, are finally apportioned among various direct production centres utilising the respective service. It is done by pricing the service and then charging each production centre, as and when appropriate, for the rendered services. Some of the examples for suitably apportioning service charges are as under:
   a. Technical service design costs on pro-rata basis are charged to appropriate work-packages/tasks for which the designs are prepared.
   b. Material services costs on pro-rata basis can be charged to the cost of materials supplied.

    c.   The 'price of concrete delivered can take into consideration all costs to be incurred by the concrete production and supply centre. The break-even prices can be adopted for calculating costs of concrete delivered, as illustrated in Section 11.3.4.

    d.   The supply of construction equipment can be charged on a pre-determined hourly rental basis.

    e.   Transportation costs of materials can be measured in terms of the quantity transported per kilometre.

The purpose of services pricing is two-fold. It enables a fair distribution of services costs, and enables a comparison of the internal services with similar services available outside the project's boundaries. However, pricing of services should be limited to major items only. Otherwise, accounting will become cumbersome.

3. **Absorb production centre's overhead costs within its work-packages.** The standard costs of each work-package of the production responsibility centre can thus be derived as under:

Direct labour cost	= A
Direct material cost	= B
Other direct expenses	= C
Direct costs (A + B + C)	= D
Share of production centre variable overheads	= V
Share of production centre fixed costs overheads	= F
Share of other centres apportioned overheads	= O
Standard production cost of work-package (D + V + F + O)	= S

In the absorption costing technique, the variable and the fixed overheads, are absorbed using pre-determined absorption rates. The absorption rate varies with each of the above overhead categories and are developed using sophisticated accounting tools like, dividing each of these overheads into three categories, i.e. indirect labour costs, indirect materials costs and other indirect expenses; and then developing a separate absorption rate for each category. However, a simplified (though less accurate) approach for computing the absorption rate is to distribute the total overheads in proportion to the direct cost of each work-package.

$$\text{Absorption Rate} = \frac{\text{Project overhead costs}}{\text{Project direct costs}}$$

$$\text{Work-package indirect cost} = \text{Absorption rate} \times \text{Work-package direct cost}$$

There will be some cases, where taking a decision to decide where to charge a particular indirect cost may appear difficult. In such cases, it is not worth wasting time on examining the merits and

demerits of various options. A near appropriate course should be adopted in this case to decide the basis on which sharing or leaving it to accountant for analysing indirect costs is based upon.

❑ 11.5 PLANNING EARNED VALUE OF WORK PACKAGES

In contracted works, Earned Value refers to the work-done value at contract rate. It determines the amount that is due on the contractor after his work is verified and accepted by the client. Earned Value Management (EMV) is a system for planning and controlling project costs. EVM establishes a work-package earned value baseline by integrating project scope, time schedule, and cost objectives. EVM is described in **Chapter 15**.

Consider the extract from the bill of quantities (BOQ), for the foundation work of a residential building complex (with actual data modified). BOQ of Foundation of a Residential Building is tabulated in **Table 11.5.**

BOQ gives the contract value of the work done, which the client has agreed to pay for the satisfactorily completed project. Work done value or sales prices for various items of work are fixed and are listed in the BOQ. As an example, **Table 3.3** (**Chapter 3**), shows an extract from the BOQ, for the foundation work of a residential building complex (with actual data modified). In the BOQ, the sale price is generally expressed in units of the work- item. But for forecasting and monitoring, it is necessary to compute the earned value or the work- done value sales price, preferably work package/activity-wise. This computation is carried out by developing a correlation between each work item and activity by breaking down an item of work into activities or sub-dividing an activity into items of works, as the case may be.

Example 1: Earned Value of Concreting of plinth wall work package. This example illustrate the splitting up of sales price of the BOQ work-item No. 8 into work package sales price.

Take the BOQ item No. A8 in **Table 3.3** relating to plinth wall concreting which represents the concrete M-250 in the plinth wall of a building module of the repetitive-type residential building construction complex. This work-item can be broken down into the sales price of connected activities for the work-package as shown in **Table 11.6**.Standard sales price of work package 'Concreting of plinth wall' expressed in work-unit of m^3 concrete placed works out as \$8031.85/43.70 = \$183.80/m^3.

Example 2: Earned Value of ground floor slab work package. This example shows the determination of sales price of work-package, representing the ground floor slab of one module from the given BOQ work item.

Determination of Earned Value of ground slab concreting work package. The Earned Value of the work package ground floor slab in work units of m^3 Unit price of concrete placed works out to \$515.82 m^3, that is:\$14648.42/28.34. See **Table 11.7** for details.

Table 11.5

Bill of Quantities: Foundation of a Residential Building (Original Modified)

Item No.	Description	Quantity	Unit	Rate ($)	Amount ($)
A1	Excavation in foundation includes disposal of earth within the work site, leveling and dressage and compaction of final source.	44,400	M^3	5.00	222,000
A2	Backfilling and compaction around foundation in layers not exceeding 30 cm with excavated earth	13,320	M^3	5.00	222,000
A3	Earth filling and compaction in plinth with approved soil in layers not exceeding 30 cm level	33,855	M^3	20.00	677,100
A4	Anti-termite treatment for bottom and sides of foundation plinth wall as per approved manufacturer's specifications	59,274	M^2	7.50	444,555
A5	Painting with 2 coats of bitumen paint to foundation sides and plinth wall surface	75,591	M^2	2.45	185,198
A6	Laying of polythene sheet 1000 G as separator between earth and concrete, and earth ad ground floor slabs	65,157	M^2	1.00	65,157
A7	75 thick blinding concrete Grade M–100 in foundation with sulphate resisting cement	1,998	M^3	95.05	189,910
A8	Reinforced concrete Grade M-250 in foundation and plinth walls with sulphate resisting cement including inserts, formwork and including expansion joints as necessary but excluding reinforcement	14,643	M^3	163.50	2,394,150
A9	Same as Item 1.8, but for ground floor slab	3,146	M^3	144.95	455,975
A10	Mild steel weld mesh reinforcement as per BS 1221 for ground floor slab	72.26	T	1,518.10	109,691
A11	High strength deformed bars reinforcement as per ASTM 1-615 Grade 60 or equivalent	673.33	T	1,095.00	737,292

Table 11.6

Contract Price Breakdown of Raft Concreting Work Package

BOQ	Activity	Qty	Unit	Rate ($)	Amount ($)
A-5	Bitumen painting	362	m³	2.45	886.90
A-8	Layout	-	-		-
A-11	Reinforcement fixing			Included in raft work package	
A-8	Shuttering and deshuttering	485	m³	-	-
A-8	Concreting and curing	43.7	m³	163.50	7144.95
Total	**Concrete placed**	**43.7**	**m³**		**$8031.85**

Note: Unit price of Concreting of plinth wall Work Package works out as $8031.85/43.70 = $183.80/m³.

Table 11.7

Determination of Earned Value of Ground Slab Concreting Work Package

BOQ	Activity	Quantity	Unit	Rate ($)	Amount ($)
A-5	Bitumen painting	319	m³	2.45	781.55
A-2	Back filling	120	m³	5.00	600.00
A-5	Plinth filling	305	m³	20.0	6100.00
A-4	Anti-termite treatment	172	m²	7.50	1290.00
A-6	Polythene sheeting	225	m²	1.00	225.00
A-9	Shuttering	11	m²	-	-
A-10	Weld mesh laying	0.651	Ton	1518.10	988.28
A-9	Concreting M 250	28.34	m³	163.5	4633.59
A-9	Curing	-	-	-	-
Total	**Concrete placed**	**28.34**	**m³**		**$14618.42**

Note: Unit price of concreting of ground floor slab work package works out as $14648.42/ 28.34 = $515.82/m³

❑ 11.6 PROJECT TIME-PHASED BASELINE DEVELOPMENT

11.6.1 Nature of Project Cost Baselines

A contractor needs various types of baselines for controlling project costs. The approved time schedule of the project, which is set date-wise in a logical sequence, is a time table for plan of action. It is an input for developing various types of project cost baselines on a calendar basis for

controlling project costs. These baselines include, forecast of budgeted value of work done and time phased planned costs of production. The time-related cumulative forecasts of the budgeted value of work done and time phased planned costs of production, when plotted graphically against the project time scale, follow the 'S' curve pattern.

In baselines 'S' curves, construction time is plotted along abscissa, and the values is represented along the ordinate axis, see **Exhibit 11.3A** and **B**.

Exhibit 11.3 A

Value of Work Done Status

Month	Planned	Actual		Certified	
Ending	Incr	Cum.		Incr	Cum.
M-01	0.00%	0.00%		0.00%	0.00%
M-02	0.00%	0.00%		0.00%	0.00%
M-03	7.50%	7.50%			
M-04	30.00%	37.50%			
M-05	15.00%	52.50%			
M-06	10.00%	62.50%			
M-07	7.60%	70.10%			
M-08	04.00%	74.10%			
M-09	5.00%	79.10%			
M-10	3.00%	82.10%			
M-11	3.00%	85.10%			
M-12	3.00%	88.10%			
M-13	0.50%	88.60%			
M-14	4.00%	92.60%			
M-15	5.00%	97.60%			
M-16	2.40%	100.00%			

11.6.2   Standard 'S' Curve Tool for Similar Projects

In the Standard 'S' Curve, both, time as well as resources axes, are divided into 100 units, which represent percentages. By doing this, the trends of projects with different cost and completion periods can be compared with each other.

To quote an example, the standard 'S' curve forecasts for value of the work done and manpower requirements of a building construction project in the Middle East, are shown in **Figure 11.3**.

The 'S' curve trends derived from analysis of large number of similar projects, such as value of work done, product costs, cash-in-flow, manpower requirement, and commonly used materials like

Exhibit 11.3 B

Value of Work Done Status Chart
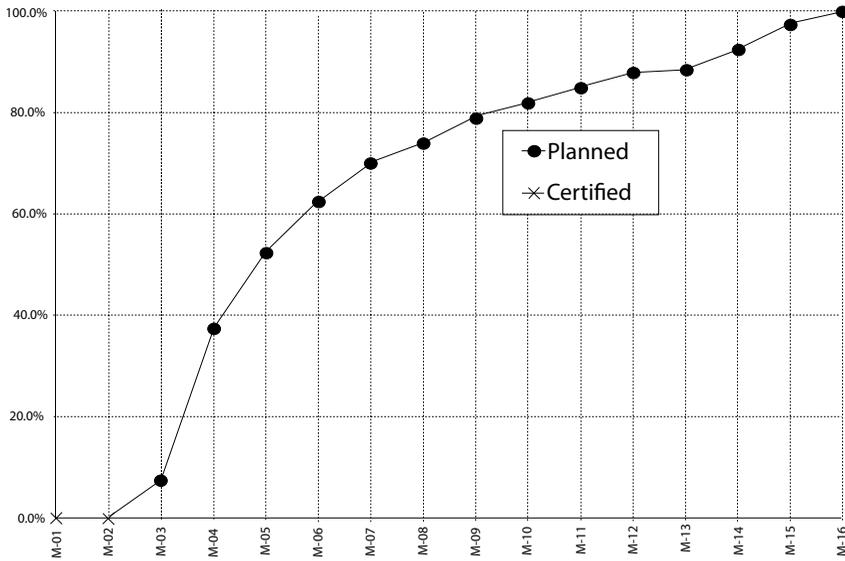
Figure 11.3

2000 housing units project typical man-months requirement and earned value S curve forecast cumulative in percentage

S-Curve Forecasts
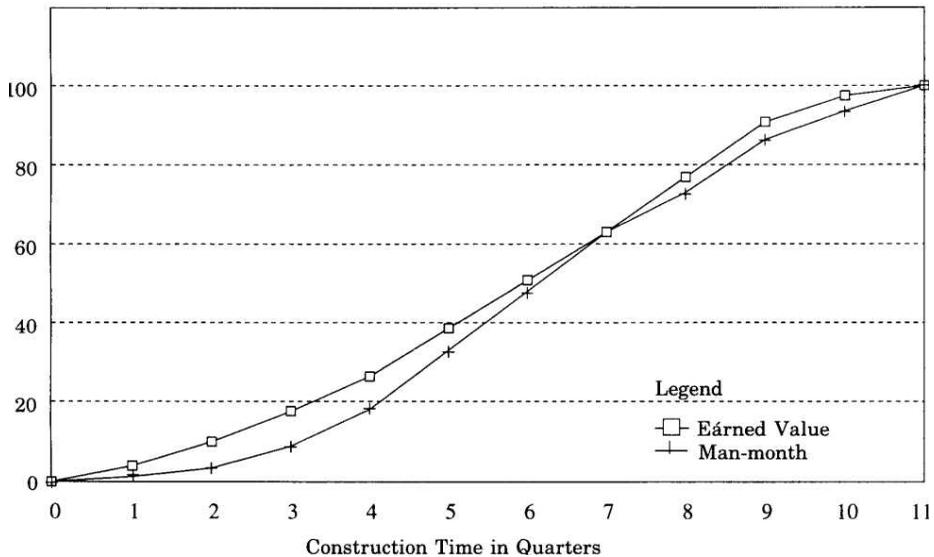
concrete; tend to follow near similar pattern. **Figure 11.4** shows the actual 'S' curve patterns of workers employment in similar building projects.

Figure 11.4

Typical 'S' curve Forecasting Tool Workers' Employment Trend Percentage Man-months employed at a given time

Man-months Cumulative (%)
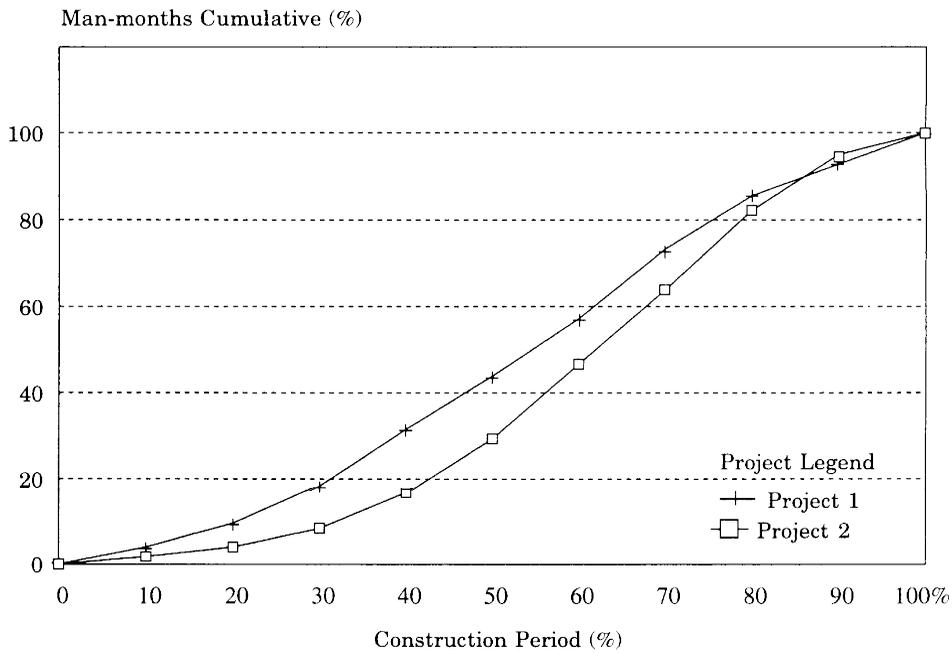
Project	Value	Duration	Man-months	Peak
1	$19.75 m	20 Months	12,375	1019 Men
2	$13.54 m	22 Months	6,945	474 Men

The 'S' curve forecasts, thus, distilled from the past performance of similar type of projects, say group housing construction, proven in practice, can thus be viewed as management tools to conceptualize resources and financial forecasts at feasibility stage. In the absence of planned forecasts, these 'S' curves can be used to conceptualize resource requirements and predict financial forecasts for formulating project objectives. In actual practice, these Standard 'S' curve forecasts may be out by 10%–30%, but it is better to have some tool for indicating forecasts rather than establishing forecasts on judgments or guess-work, by individuals. It may be noted that the preparation of the Standard 'S' curve forecasts is an art as well as a science. While, the methodology outlined above provides a scientific approach, its application needs experts. It is again emphasized that this sophisticated 'S' curve forecasting device cannot be left in inexperienced hands and should not be considered as a mathematical jugglery. It needs competent planners for scrutinizing past performances, formulating variances during execution, and reasoning variations from the Standard 'S' curve forecasts.

APPENDIX K

Breakeven Analysis

❑ K.1 INTRODUCTION

The term break-even analysis is interpreted in a narrow as well as broad sense. Used in its narrow sense, it is concerned with finding out the break-even point. Break-even point is the point at which total revenue is equal to total cost, i.e., the point of no profit no loss. In its broad sense, break-even analysis means a system of analysis that can be used to determine the probable profit at any level of production.

At project site, break-even analysis can be used to determine the cost of services rendered by various service responsibility centres. Costing depends upon the nature of service rendered. For example, the service centre like 'materials transporting centre' will have to go into service costing to calculate the charges per km of product transported. Similarly, the 'equipment supplying centre' will need to work out the owning and operating costs in order to determine the hiring charges, which is to be levied against the responsibility centre utilising this service.

❑ K.2 BREAK-EVEN ANALYSIS METHODOLOGY

Break-even analysis involves establishing of the relationship among the three variables, i.e. sales price, production volume, and profit. Break-even analysis can be done in both the manners, graphically as well as analytically. Graphically, the three variables can be represented as under:

For example, price at which site manufactured ready-mix concrete is to be supplied to the user responsibility centre (say by the Production Centre to the Foundation Construction Centre) can be determined by computing the break-even point. Let us consider the capacity of the Ready-mix Concrete Production Centre to supply concrete as 2500 CM concrete per month, working 10 hours per working day. The concrete production cost data for 2500 CM consists of variable costs (V) at SR 121.95 per CM and fixed costs (F) at SR 69 625 per month. The cost breakdown is explained in detail as below:

Considering the above example, analytically the break-even price of ready-mix concrete can be calculated as under:

Let,

V = Variable cost of one month production
= Variable cost per CM × Quantity manufactured and delivered during the month
= v × q = SR121.95 × 2500 CM

Break-even point
at 2500 m³

Break-even
point

Sale value

} Marginal
profit

Standard sale price

Variable Costs

Fixed
costs

Margin
of Safety

2500 m³   3000 m³
Monthly Supply Volume
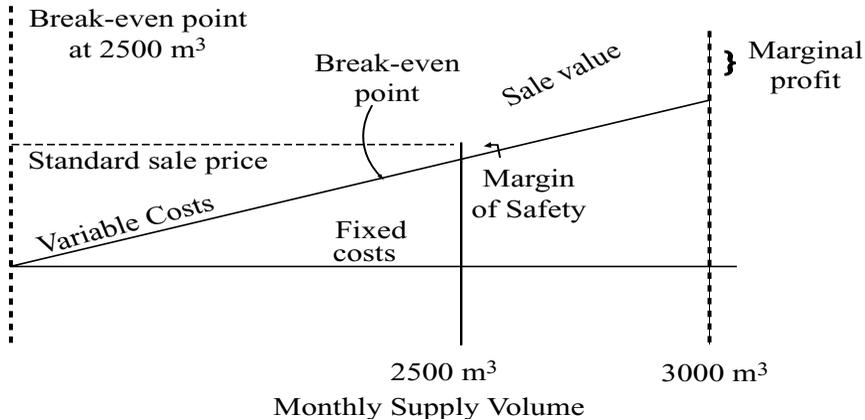
Cost of Production of One Cubic Metre Ready-Mix Concrete

	Cost (SR) per m³	Variable per m³	Fixed per month
A. Material Cost			
1. Cement	81.30		
2. 3/4 aggregate	10.45		
3. 3/4 aggregate	4.80		
4. Washed sand	6.05		
5. White sand	4.20		
6. Water	1.20		
Total	108.00	108.00	
B. Manufacturing and Transportation Expenses			
1. Manpower costs (all permanent categories)	17.30		43 350
2. Repair & maintenance (based on past records)	10.05	10.05	
3. Oil, diesel & lubricant (based on past records)	3.90	3.90	
4. Administration costs	3.15		7875
5. Insurance	0.60		900
6. Contingencies	2.00		5000
7. Depreciation	5.00		12 500
Cost of production and transportation in SR	150.00	121.95	69 625

Note. The above costing is based on monthly supply of 2500 Cubic Metres

F = Fixed cost per month = SR 69 625

S = Sales value for one month production

$$= \text{Sale price per CM concrete} \times \text{Quantity delivered}$$
$$= p \times q = p \times 2500 \text{ CM}$$

Then, at break-even, for 2500 CM concrete supply,

$$S = V + F \text{ Or}, p .q = v . q + F \text{ Or}, p = v + F/q$$

Therefore, price/M³ (p) to break-even for monthly 2500 CM delivery with variable cost of SR per cubic meter and fixed cost of SR per month is:

$$p = 121.95 + 69\ 625/2500 = \text{SR } 150 \text{ (approximate)}$$

Note that the budgeted sales price is estimated for assumed and most frequently occurring level of deliveries. Higher volume of delivery can thus, yield marginal profit to cater for contingencies.

❑ K.3   ASSUMPTIONS AND LIMITATIONS

Break-even analysis establishes a relationship among the three variables, i.e. sales price, production volume, and profit. It can highlight the effect of changes in any of these parameters. But it is based on certain assumptions and certain limitations which include:

1. All costs are categorised into fixed and variable costs. This in practice is difficult. Further, the concept of   variability varies with situation. The break-even analysis for a given situation may not hold good for another similar situation.
2. The fixed cost and the rate of variable cost of each unit of production remains constant even with the rise in production volume, though in practice this may not be true.
3. Variable costs will fluctuate in direct proportion to the volume of output. Generally, these assumed linear relationships of various parameters, it may take the shape of curves instead of straight lines.
4. Selling price, production quantity, productivity will remain constant, but this may not be true always.
5. The above example considers one grade of concrete production, but in practice, each activity has a product-mix, and a construction project that consists of wide and varied types of activities.

❑ K.4   USES OF BREAK-EVEN ANALYSIS

In spite of its limitations, the break-even analysis is a useful management device when it is developed. Scientifically prepared from reliable data, break-even analysis is useful for:

• Determination of the sales price, which will give the desired profits;
• Fixation of sales volume level to cover a given return on capital employed;

- Forecasting costs and profits as a result of change in volume;
- Suggestions for shifts in sales mix;
- Inter-firm comparison of profitability;
- Determination of costs and revenue at various levels of output; and
- Impact of increase or decrease in fixed and variable costs on profit.

In construction practices, break-even analysis should be viewed as guidelines for making decision.

Contractor's Construction Budget

A project budget reflects the financial plan of operations, divided into responsibility centres, with specific goals clearly outlined along with costs expected to be incurred. The primary purpose of having a budget is to assign financial targets and resources to each responsibility centre, to coordinate their activities, to form the basis for controlling performance, and to make the participant cost conscious instead of purposeless routine accounting.

The budget uses the language of accounting to state objectives and measure performance. The project budget integrates monetary objectives, responsibilities and allocated resources. The project functional organisation is structured into responsibility centres. Each responsibility centre is assigned goals in the form of the earned value or earned values budget. It is allocated resource in the form of materials, labour, equipment and budgeted cost for assigned goals. Finally, the project financial plan is presented in the form of the master budget, which summarises all the budget information like profit and loss statements, balance sheets, capital expenditure budget, cash flow forecasts and performance indicators.

Project Cost Budget is a project-directing, authority-approved estimate of the expected revenue, expenses, resources associated and achievement-target instrument. The budget estimated costs are broken down into various heads of accounts such as planning units generally stated in terms of work packages, resource allocation, expected revenue, cost and time, completion targets to be achieved, and responsibility for accomplishing the targets. Budget status is reported, monitored and controlled in accordance with the specified performance accounting system generally expressed in monetary terms.

Unless otherwise specified, typical project budget comprises of the following components:

$$\text{Total project budget} = \text{Cost baseline} + \text{Management reserve}$$

Where,

Cost baseline   =   Control account
                =   Contingencies reserve + Work package cost estimates

Total Project Budget	Management Reserve		
	Cost baseline	Control accounts	Contingencies reserve
			Work package cost estimates

Project Budget Components

The project cost baseline is the approved version of the time-phased project budget excluding management reserve. Management reserves generally are not included in a project manager's budget. This chapter confines to project manager's budget and excludes management reserves. Management reserve is discussed in **Chapter 17**.

In a construction project, the client and the contractor have separate budgets. Although, the project schedule of work and earned value (or work performed value) form the common baseline for developing these budgets, their purpose differs.

The client's construction budget is primarily a capital budget. It is what the client has earmarked for the project. It includes the expenditure on preliminaries, procurement of land, client supply resources, consultant's fee, contractor's cost and the cost of working capital. Client cash flow forecasts time-phased funds requirement and the sources from which these funds are to be provisioned. On the other hand, a contractor's budget is earned value revenue and resources expenditure oriented. It includes quarterly statements of revenue and expenditure and forecast of financial statements of projected balance sheet, cash flow, profit and loss and performance measuring baselines.

The contractor's project budget-making process goes through the following stages:

- Structuring responsibility centres;
- Budgeting earned value targets and assigning these targets to the respective responsibility centre;
- Budgeting production expenses necessary for the fulfillment of assigned tasks of each responsibility centre;
- Provisioning for inflation and escalation;
- Forecasting profit and loss, cash flow statement and balance sheet; and
- Preparing a project master budget.

Salient features of the contractor's budget development are briefly described in subsequent paragraphs. This chapter covers the following sections:

1. Contractor's Project Manager Budget
2. Structuring Responsibility Centres
3. Earned Value Budget (Revenue Budget)
4. Operating Expenses Budget
5. Indirect Costs Budget Including Cost Inflation, Escalation and Contingencies
6. Budgeted Financial Forecasts
7. Essential Features of an Effective Project Master Budget

❑ 12.1 CONTRACTOR'S PROJECT MANAGER BUDGET

Client's contract documents for major projects are generally received, estimated, tendered, negotiated and finalised by the contractor's corporate office. After the award of the contract, the corporation

breaks down the contracted amount into corporate contract budget (CCB) and a major part of this amount is allocated to project manager for execution of the project in the form of Project Manager Budget (PMB).

The contractor's budget is a sub-set of Corporate Budget. Its accounting heads generally conforms to the Corporate Project Budget. The breakdown of a typical Contractor Construction Budget is shown in **Figure 12.1**.

Figure 12.1

Project Construction Budget Breakdown
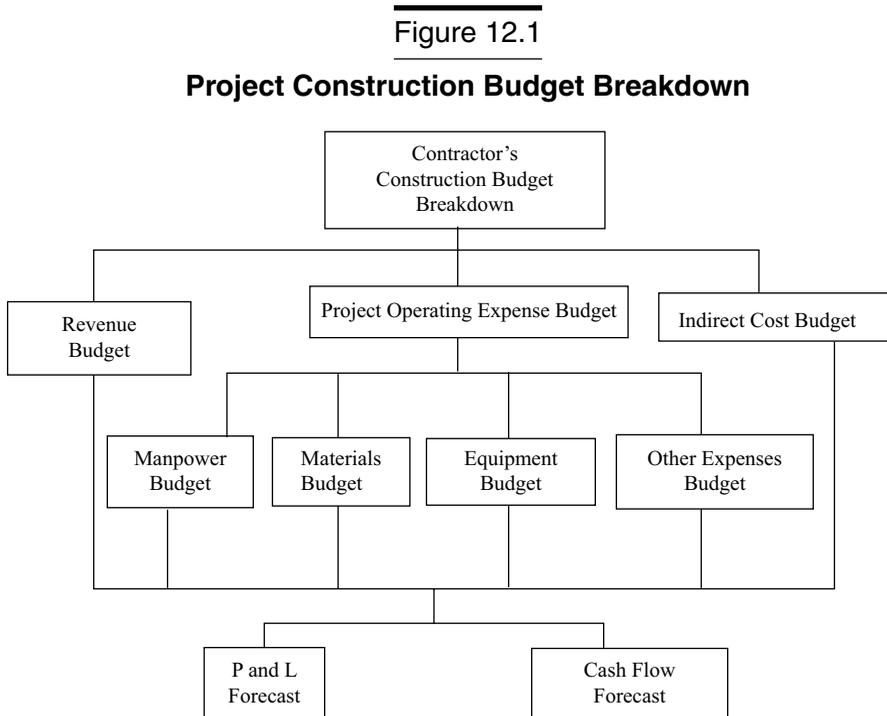
Note: Indirect Costs can be further divided into project site indirect cost, corporate overheads and corporate reserves.

Both CCB and PM budgets follow the corporate cost accounting system to state objectives and measure performance. These budgets adopt common computerised accounting system. Cost breakdown in the accounting system generally follows similar classification, codification, grouping, assigning resources, accounting, allocating responsibilities and reporting and monitoring policy. An outline summary extract from a typical corporate contract and project management budgets are tabulated below:

❏ 12.2 STRUCTURING RESPONSIBILITY CENTRES

Project objectives are linked with the performance of a number of result-oriented organisational units. These units are structured according to their task-responsibility-reporting relationship, as can be seen in **Exhibit 12.1** depicting the organisational chart of the housing units project. The number

Table 12.1

Outline Allocations of Corporate Contract and Project Management Budgets (in Rs. 1000)

Act Codes	CCB Items Description	CCB Amount	Reserve Amount	PMB Amount
(a)	(b)	(c)	(d)	(c–d)
DMSC00000	Direct Materials Supply category-wise. It includes costs of purchase, transportation, insurance etc., of material items like Electrical, Mechanical, Electronics, E&M, Instruments, Plumbing, HVAC, Concrete, Steelwork, Site-manufactured Woodwork etc., as per corporate master list.			
DLTC00000	Direct labour tradesmen category-wise. It includes cost of recruitment, accommodation, lodging and boarding, wages, leave entitlement, medical etc. as per company policy.			
DSCT00000	Direct sub-contractor task-wise. It includes each sub-contractor prime-costs.			
ENGC00000	Engineering Costs. It includes services like investigation, designing, drawing, consultancy etc.			
ENGG00000	Architecture, designs and drawings necessary for execution of the project. It includes special technical consultant services such as investigation/trials.			
INDC00000	Indirect costs. It includes costs of pre-contract activities, management, supervision, office expenses, general plant and machinery, transport, accommodation, utility services, minor tools and equipment, travel and entertainment expenses, head office allocation etc.			
CONT00000	Contingencies including risks and management reserve			
MARG00000	Margin			
Total				

Note: Sum of Corporate Contract Budgeted = PM Budget + Corporate Overheads + Corporate Reserves
= Contract Quoted Value

of organisational units depends upon the magnitude and complexity of the project. A simple project may have only a few organisational units whereas a large number of interacting organisational units are required for a large complex project. In a major project, each organisational unit is usually headed by a manager.

In construction projects, as already explained in **Chapter 7**, Responsibility/Costs centres can be broadly divided into three categories viz. construction (or production) centres, support service centres, management and administration centres. To quote an example, the Responsibility/Cost Centre of 2000 Housing Units Project are depicted in **Exhibit 12.2**.

Exhibit 12.1

2000 Housing Units Project: Organisation Chart

```
                        ┌─────────────────────┐
                        │   General Manager   │
                        ├─────────────────────┤
                        │       Project       │
                        └─────────────────────┘
          ┌───────────────────────┼───────────────────────────┐
┌─────────────────────┐                          ┌─────────────────────┐
│   Deputy General    │                          │   Deputy General    │
│      Manager        │                          │      Manager        │
├─────────────────────┤                          ├─────────────────────┤
│     Technical       │                          │    Construction     │
└─────────────────────┘                          └─────────────────────┘
   │      │      │       │
┌────────┐┌────────┐┌────────┐┌──────────┐
│Planning││Contract││Costing ││ Design & │
│        ││        ││        ││ Drawings │
└────────┘└────────┘└────────┘└──────────┘
```

Materials Management | Administration & Personnel | Finance | Internal Auditor | Medical

Manager Prefab | Manager Finishes | Manager Buildings | Manager External Services | Manager Manufacturing | Manager Mechanical | Manager Quarrying | Manager Quality Control

❑ 12.3   EARNED VALUE BUDGET

The earned value or sales value of the work-in-progress yields revenue. This revenue in turn nourishes the growth of the project. Without regular earned values revenue, a project cannot survive. It is the earned values forecast that forms the base for the quantification of the entire production budget. Therefore, it is imperative that all those engaged in project management and specially, the functional heads of the production centres should take an active role in the formulation of the earned values budget.

The first step in the earned value budget preparation is to develop the monthly physical targets to be achieved. These physical targets are stated in the form of planned progress of work packages. These targets are derived from the project schedule of work.

The earned values forecast of the monthly value of work done can then be computed by assigning standard earned value for each work-package, and then aggregating these month-wise to derive the work done earned value. This process, described in **Chapter 6** and **Chapter 11**, enables the preparation of earned value forecast for the project.

The earned value forecast is a prediction of the anticipated value of work planned which may or may not come through. The earned values forecast need not necessarily be the management's

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Exhibit 12.2

2000 Housing Units Project Task Responsibility Centres

Project Management

Construction Responsibility Centres

- Building Foundation Centre.
- Building Finishes Centre.
- Precast Erection Centre.
- Public Building Centre.
- Pavement Construction Centre.
- Landscaping Centre.

Services Responsibility Centres

- Precast Concrete Production Factory
- Readymix Concrete Production Plant.
- Steel Fabrication Shop.
- Quarrying Establishment.
- Plant & Machinery Maintenance Unit.

Management and Administration Responsibility Centres

- Administration & Personnel Management.
- Materials Management.
- Plant & Machinery Management.
- Finance Management.
- Cost Management.
- Engineering Services Management.
- Contract Management.
- Planning and Monitoring Cell.

earned values budget. The earned values budget implies commitment. It lays down the earned values revenue to be achieved. The committed monthly earned values projections for each production centre are generally derived after critically examining the schedule of work and the connected earned values forecast by taking into consideration the complexities and characteristics of the project and the terms and conditions for payment by the client.

A typical format used for the computation of the monthly revenue budget is given below and its preparation method is explained in subsequent paragraphs.

(A)	Stipulated receipts of earned values value of work done	xx
(B)	Less retention as per contract	(xx)
(C)	Receipts from earned values (A-B)	xx

(D)	Add for materials at site as per contract provisions	xx
(E)	Add for extra work, if any	xx
(F)	Less pro rata recovery for advance	(xx)
(G)	Monthly amount payable by client	xx
(H)	Add other incomes (earned values of extra work, etc. if any)	xx
(I)	Net monthly revenue projection	xx

In practice, contractors are given on-account payments in the form of advance for work done and materials delivered on site at regular intervals of time according to the terms of contract, and the contractors do not have to wait for payment till the final completion of the contract. A typical 'Advance Payment Application' form, specified by a client for use by the contractor, is shown in **Table 12.2**.

Table 12.2

Monthly Interim Payment Application Typical Format

Client: (Name and Address)
Contractor: (Name and Address)
Contractor No. and Description: ………………
Contract Amount:…………………………   Change Order Amount:…………
Total Amount:…………………………….   (In words
Interim Payment No. ……………………...   Period:………………………….)

	New Accumulated	Previous Accumulated	This Period
Earned Value Summary			
Work contracted			
Extra works			
Less retention			
A-Workdone Payable			
Materials-at-Site Value			
B-Materials Payable			
Advance Payment			
Amount advanced			
Less amount refunded			
C-Advance Payable with this Bill			
Payment Status			
Total amount payable (A + B + C)			
Less Amount already paid			
Balance due			Amount in words
Sign	Stamp of the		Sign
Contractor	Contractor		Approved by Client
(Name and Status)			(Name and Status)
Date			Date

Enclosure: Back-up details of Original Works Valuation, Extra Work done Statement and Materials-at-site sheet.

A payable amount, usually includes work done value plus material at the site, less retention (5%-10% of work done to contractor), all as per the terms of contract. Normally, the payments are to contractor made by the client on a monthly basis and the predetermined mode of payment is incorporated in the contract documents. The payment evaluation is generally carried out by measuring the percentage work completed, the work-in-progress and the permanent works materials brought at the site by the contractor. In order to determine the value of work done, the measured quantities of work completed and work-in-progress are multiplied by the unit earned value price for each work-item completed and work-in-progress:

Value of work done   = Value of work completed + Value of work in-progress.
Where,
Value of work completed = Sum of product of unit earned value price multiplied
         by respective quantity of work done.
Value of work-in-progress = Value of payable work-in-progress
         at assessed split rate of earned value price.

The advance for materials at the site are paid at a predetermined percentage (say 70%) of the materials' purchased price. Most of the contract conditions provide for the retention of a certain amount (say 5% of the value of work done) as a performance guarantee. Further, proportionate deducti ons are also made for the mobilisation advance if paid by the client (according to the contract) prior to the commencement of the work. Finally, the earned values budget for the value of work are plotted in the pattern of cumulative 'S' curve graphs as shown in **Figure 12.3**.

It may be noted that the stipulated date of receipt of the payment from the client against the earned values invoice is a critical factor in the computation of the earned values budget and cash flow. Although the progressive monthly payment invoices do get scrutinised by the client engineer at construction site within a week of submission by the contractor, but depending upon the terms and conditions of the contract it may take anything from two weeks to more than a month for the payment to reach in the contractor's bank account. It is the date of receipt of the money, which is considered in the cash-flow budget, and not the date of the invoice for payment.

❑ 12.4 PROJECT OPERATING EXPENSE BUDGET

Project operating cost of accomplishing planned tasks in a given accounting period can be determined by summing up the standard costs of corresponding work-packages constituting the tasks. The well designed standard costs are adequate for forecasting the expenditure and controlling the costs of work-packages but these can be further refined for budgeting, coordinating, communicating and controlling the tasks and overall resources assigned to the responsibility centres.

The project operating expense budget details the resources and costs planned for achieving phased objectives. In simple words, it can be termed as an 'expenditure budget'. While detailing, the expenditure is considered on a monthly basis. The accounting period while preparing the budget is generally taken as quarterly. The project accounting period is matched with the reporting period as well as the corporate accounting period so as to avoid duplication.

12.4.1   Types of Budgets and Schedules

An expense budget comprises of a number of budgets and schedules as shown in **Figure 12.2**.

Figure 12.2

Expense Budget Breakdown
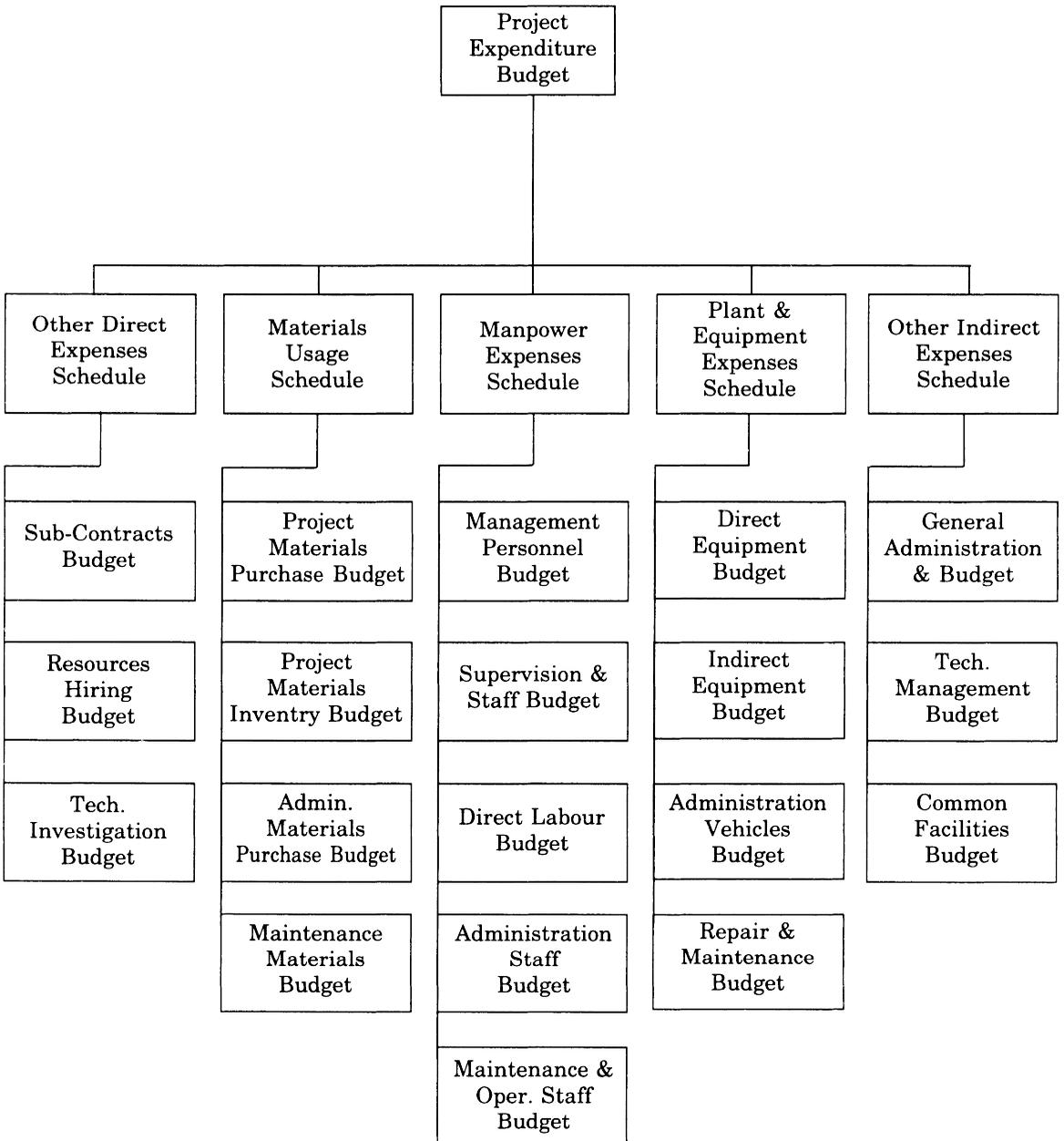
Project expenditures can be broadly divided into two categories, i.e. production-related expenses and administration-related expenses. The production costs budget, which accounts for production related expenses, includes budgets for each of the production responsibility centres and the services responsibility centres who support the production. The administration expenditure budget consists of the general administration budget, technical management budget, and temporary work and common facilities budget.

The basis of preparation of the budget of production-related responsibility centres is the specified production physical and financial targets to be accomplished during each accounting period. These physical targets are stated in terms of work-packages to be completed, and in case of service centres, the physical targets quantify the services to be rendered. The physical targets are converted into earned values targets at predetermined rates derived from the bill-of-quantities or specified service charges.

The administration related expense budget accounts for the expenditure planned for the project command and control setup, and the project temporary works and common facilities. These costs can be further divided into general administration expenses, technical management expenses and common facilities expenses.

The making of a project expenditure budget starts with the budgeting of resources for each service centre. The service centre's earned value price or service charges, where feasible, are then incorporated while preparing the budget for each production centre. These production and service centres' budgets are then added up to the administration centre's budget to develop the project operating expense budget. The nature of budgets prepared at each responsibility centre is listed in **Exhibit 12.3**.

Each responsibility centre as well as the combined project expenditure budget is reflected into schedules and sub-budgets.

These schedules include the following:

a.   Project manpower expenses schedule;
b.   Project materials usage cost schedule;
c.   Plant and equipment expenses schedule; and
d.   Other direct expenses schedule

Project Manpower Expenses Schedule.   Project manpower expense schedule represents the phased manpower costs of the entire project. This budget comprises of the manpower expense sub-budgets of all responsibility centres.

This schedule can be divided into the following categories:

1.   *Management personnel budget:* It includes the managers' salaries and their associated expenses.
2.   *Supervisory and site staff budget:* It represents the manpower costs of the technical supervisors and site staff employed in the production and service responsibility centres.

<div align="center">

Exhibit 12.3

2000 Housing Units Project Budget Allocations

</div>

S. No.	Category of budget	Construction task forces				Service centres						Adm. centre
		Fndn.	Str.	Fnsh.	Srvs.	Perso. Mgt.	Mtrl. Mgt.	Tech. Mgt.	Fic. Mgt.	P and M Mgt.	F and Mgt.	
1.	Earned values Budget	x	x	x	x.						x	
2.	Direct Cost Budget											
	(a) Direct Labour	x	x	x	x						x	
	(b) Materials	x	x	x	x						x	
	(c) Other expenses	x	x	x	x							
3.	Indirect expense Budget											
	(a) Indirect manpower	x	x	x	x	x	x	x	x	x	x	x
	(b) Indirect materials	x	x	x	x	x	x			x	x	x
	(c) Indirect plant and Machines	x	x	x	x	x	x			x	x	
	(d) Administration expenses								x		x	
	(e) Depreciation									x		

3. *Direct labour budget:* It cover the direct labour cost employed in the production centres and product manufacturing service centres. This manpower strength constitutes the majority of the personnel employed at the project site.
4. *Equipment maintenance and operation staff and workers:* It covers all categories of manpower both direct and indirect employed in the plant and equipment responsibility centre.
5. *Administration staff budget:* It consists of the indirect manpower employed in the administration and resources management set-up, other than already covered by the management personnel, supervisory staff, equipment repair and maintenance manpower (if not catered separately). It includes the personnel administration staff, project office manpower, technical staff, and common utility services manpower.

A typical direct manpower schedule format is shown in **Table 12.3**.

Table 12.3

**Manpower and Connected Expenses Budget:
Typical Format for Quarterly Summary**

S.No.	Manpower Category	Quarter No.				
		No.	Salary/Wages	Bonus/Overtime	Connected Expenses	Total
	Establishment					
1.	Manager					
2.	Senior engineers					
3.	Junior engineers					
4.	Staff grade 1					
5.	Staff grade 2					
6.	Staff grade 3					
	Direct Workers					
7.	Foreman					
8.	Charge-hand					
9.	Specialists					
10.	Highly skilled					
11.	Skilled					
12.	Semi-skilled					
13.	General helpers					

Notes: Connected expenses breakdown include mobilisation costs, messing, medical, accommodation, conveyance leave entitlement, social and terminal benefits, welfare. etc., as applicable.

Project Materials Usage Cost Schedule.   The usage schedule of materials is compiled from usage requirements of materials projected by the responsibility centres. Based on these requirements, the following budgets are prepared:

- Project materials purchase budget;
- Project materials inventory budget;
- Administration materials budget; and
- Maintenance materials budget.

In particular, the project materials purchase budget takes into account the materials' consumption as reflected in the materials' usage schedule and the planned materials inventory at the end of each accounting period. The typical format for developing materials budget is indicated in **Table 12.4**.

The materials' purchase budget indicates the time, quantity, and cost of materials to be purchased. The purchase budget is prepared after considering materials usage and inventory requirements,

Table 12.4

Construction Materials Budget Summary: Typical Format

S. No.	Type of Materials		Estimated Cost				Quarter No. 1 Cost			……..	Last Quarter Cost			Remarks
	Name	Code	Unit	Quantity	Unit Rate	Amount	P	U	I	……..	P	U	I	
	Material A									……..				
	Material B									……..				
										……..				
	Total									……..				

Abbreviation: P = Materials procurement planned amount, U = Material usage cost,
 I = Materials quarter ending inventory

prevailing relevant market factors, the shelf life characteristics of materials, and warehouse capability. The materials' purchase budget is of great significance, as materials constitute over 50% of the project expenses.

Plant and Equipment Expenses Schedule.   Plant and equipment budget includes all owning and operating costs of the plant and equipments, and vehicles employed at the project site. Generally, the manpower like mechanics, operators and drivers, spare parts, repair and maintenance materials are budgeted separately as their procurement is done by the personnel and materials departments. The plant and equipment budget can be broadly divided into the following categories:

- Direct plant and equipment budget;
- Indirect plant and equipment budget;
- Administrative vehicles budget; and
- Repair and maintenance budget.

the typical format for developing plant and equipment budget is reflected in **Table 12.5**. Keeping in mind the budget and feasibility, employment of each equipment should be accounted for in terms of predetermined hire charges for the period (in hours) it is physically employed at the site.

Other Direct Expenses Schedule.   In addition to manpower, material and equipment costs, some responsibility centres also incur expenditure, which can be identified with the execution of permanent works. The type of such expenses will vary from project to project. However, the following are some of the other direct expenses which need budgeting:

- Sub-contracted works;

Table 12.5

Equipment Usage Budget Summary: Typical Format

S. No.	Type of Equipment		WDV	Expenditure Basis			Quarter No. 1					...	Last Quarter					Remarks
	Nomenclature	Code		Efforts	Rate	Total	D	R	M	F	To-tal	...	D	R	M	F	To-tal	
1.	Equipment A																	
	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
Total																		

Abbreviation: WDV = Work-Down Value/Purchase Price, D = Depreciation payable, R = Repairs/Spares/Replacement costs, M = Specific maintenance cost, F = Fuel, oil and lubricants.

- Resources of manpower and equipment, which are planned to be hired from external sources;
- Technical studies like soil investigations; and
- Professional fees for the preparation of designs, drawings, etc.

❑ 12.5   INDIRECT EXPENSES BUDGET

12.5.1   General and Administration Expenses Schedule

This schedule includes all other indirect expenses, which are not included elsewhere during budgeting. Such indirect expenses, which mostly result from administrative functions, can be broadly divided into the following three main heads. Each of them can be budgeted separately:

- General administration expenses;
- Technical management expenses; and
- Temporary works and common facilities expenses.

a.   General administration expenses cover management personnel costs, project office costs, computer system costs, and costs of resource management departments like personnel, materials, plant and equipment, and finance.

b.   The technical management expenses cover:

- Technical office staff including designers, quantity surveyors, draftsmen and certain special categories of workers;
- Technical office equipment, instruments, publications and special stationery;
- Contracts and sub-contacts preparation administration costs;
- Designs and drawings preparation expenses;
- Quality control costs; and
- Project planning and controlling costs.

c.   Temporary works and common facilities expenses cover accommodation, utility services, HVAC, roads and fencing, mess or food services, sports and recreation, etc.

In case of a small-size project, cost heads listed in **Table 12.6** can be used to develop the general and administration budget.

12.5.2   Cost Inflation, Escalation and Contingencies

Inflation and escalation are two common terms that are often misunderstood. Inflation results in an increase in the prices of goods and services, and thus gradually decreases the purchasing power of money. On the other hand, escalation in a project work can be taken as the difference between the original and the latest estimate of the final cost of the project. It includes cost changes, which were not anticipated at the time of preparation of the original estimate. Generally, unforeseen expenditures are covered in project contingencies. In some construction contracts, provision for inflation is made in the contract clause in terms of increase or decrease of a certain price index such as the

Table 12.6

General and Administration Budget—Quarter-wise Summary: Typical Format

S. No.	Expenses Category	Amount
1.	Establishment (not covered elsewhere)	
	(a) Salary/wages	
	(b) Bonus/overtime/incentive	
	(c) Connected manpower expenses	
	(d) Welfare and other expenses	
2.	General Expenses	
	(a) Office expenses	
	(b) Travelling	
	(c) Entertainment	
	(d) Audit fees	
	(e) Legal and other services	
	(f) Bank charges	
	(g) Bad debts	
	(h) Miscellaneous	
3.	Period Expenses	
	(a) Office rent, taxes etc.	
	(b) Insurance	
	(d) Depreciation	
4.	Fixed Expenses	
	Interest on loans and borrowings	
	Total Quarter	

consumer price index, wages price index or construction cost. These indices are published regularly by Government and other autonomous organisations and federations. Some of the companies also develop the company cost indices for monitoring and forecasting cost changes, and pricing tenders to cater for inflationary tendencies, potential marketing trends and business environments. However, there is no hard and fast method to estimate the effect of inflation on the project costs, as the variables involved are too many.

To quote an example, if the rate of inflationary trend is less than 5%, then it need not be considered, as the contractors generally make allowances for contingencies (say up to 5% of the direct

cost) to cater to such eventualities. It may be noted that the anticipated inflation gets compounded every year. For example, if the inflationary trend during the current year is 10% per annum, the forecast for the next year with the current trend of inflation at 10% will be 11%, with an average rate of increase in two years at 10.5% per year.

Assumed current price	= 100
Anticipated inflation during the current year	= 10%
Assessed price at the end of the current year	= $100×(1+0.10)
	= $110
Forecasted rate of inflation for the next year	= 10%
Assessed price at the end of the next year	= 121, i.e. 110(1+0.10)
Therefore, the average price rise in two years from the Current price level of $100	= (121–100)/2=10.5%
Average price rise during the second year at the current Price of $100	= $(121–110)= $11.0

The inflationary trend can be reviewed at the time of the review of budget and the cash flow forecast can be modified by taking the then prevailing trend of prices.

❏ 12.6   BUDGETARY FINANCIAL FORECASTS

12.6.1   Financial Statements

The major Financial Statements which result from the accounting process are 'Profit and Loss Account', 'Cash Flow Statement' and 'Balance Sheet'. Profit and Loss Statement prepared during budgeting process depicts the anticipated revenue and expenditure account. A cash flow forecast outlines the expected cash inflow and the monetary outflow. The project balance sheet forecast can be broadly divided into anticipated 'Assets' and 'Liabilities.' The forecast of these financial statements can be made on quarterly basis.

12.6.2   Forecasting Profit and Loss

Business motive is to make profit. A business firm needs profit to cover its risks, to assist in its growth and to meet the financial needs of its stakeholders, directors, staff and workers. A construction firm takes risks when it tenders for a project and, after winning the contract, it expects a reward in the form of calculated profit which is expected to be higher than what it can get through safe investments like bank fixed deposits and government bonds and securities. In this process, the construction firms also face the risk of losing money. Higher profit projects usually involve more risk and greater uncertainty. The profit and loss statement depicts the profit or loss resulting over a specified period.

While undertaking a construction project, the company estimates its profit and defines its profit objectives. These profit objectives lead to a more practical and systematic approach for making

profit. On the contrary, the maximisation of profit is generally not the objective of professional companies. Maximisation concept is bound to go directly against the company's values as this may involve overlooking administrative policies, violating statutory regulations and adversely affecting the trade reputation. However, in construction business, it is not unusual for a contracting firm to make a bid without prospects of profit in an odd contract so as to prevent idling of resources and to maintain the continuity of business. On the whole, efficient management leads to profit whereas losses can be viewed as a case of penalty for inefficient handling or incorrect estimation of profit objectives.

In accounting practices, gross operating profit before taxes is computed as under:

1.0	Revenue		
1.1	Earned values value of work done	xx	
1.2	Other revenues	xx	
			xxx
2.0	*Less direct production cost of work done*		
2.1	Direct labour costs	xx	
2.2	Direct material costs	xx	
2.3	Other direct costs	xx	
			(xxx)
3.0	*Gross margin* (Sl. 2.0–Sl. 1.0)		xx
4.0	*Less overhead expenses*		
	Indirect variable costs	xx	
	Indirect fixed costs	xx	
			(xx)
5.0	*Gross operating profit or loss* (Sl.3.0–Sl. 4.0)		xx

Assuming that in project execution, non-operating income is negligible, the gross operating profit at a given point of time can be determined by evaluating the difference between the total earned values and the total costs of earned values at that point of time:

Gross operating profit = Earned values revenue – Cost of production

Generally the gross profit can be forecast by plotting the cumulative effect of earned values revenue and production costs in the project time-related 'S' curve chart. In this chart, the project time duration is scaled along abscissa and the monetary values are scaled along the ordinate axis. The schedule of project work forms the basis for plotting 'S' curves representing the cumulative effect of earned values revenue and the cumulative production costs. The method of plotting these 'S' curves is dealt with in **Chapter 11**.

A typical 'S' curve pattern graph of cumulative earned values and cumulative production costs of a project are shown in **Figure 12.3**. The extent of profit (or loss) at a given point of time can be estimated by measuring the vertical gap in monetary value between the cumulative earned values and cumulative production cost curves.

Figure 12.3

'S' Curve Pattern Graph of Cumulative Earned and Cumulative Production Costs of a Project

Financial Trends
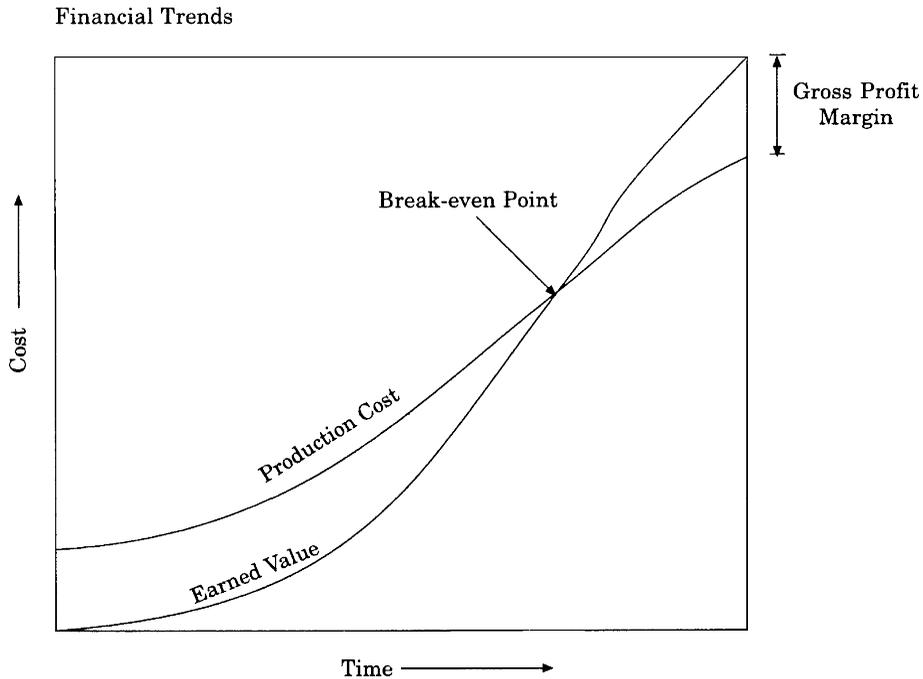
The point of time at which the cumulative earned values curve intersects with the cumulative production cost curve is termed the project break-even point and the time at which break-even occurs is called the project break-even time. The project break-even point shows the no-profit-no-loss situation, and after the break-even time, the project trend changes towards making profit.

In the initial stages of the project, till break-even point is reached, the production costs are higher than the earned values revenue. This period of cash loss or negative profit, which may stretch beyond half-life of the construction period and may call for the mobilisation of cash resources to meet the inadequacy of funds?

It may be noted that the forecasting of profit is a touchy subject, which needs careful handling due to the inherent uncertainties and complexities in the nature of construction projects.

Actual profit, if lower than the profits forecasted, can create unpleasant situations specially, when the profit reporting is carried out too frequently as fluctuations in forecasts can create conflict and confusion. Moreover, profit reporting has to be done and it cannot wait till the completion of the project. Further, it is not feasible to account for all factors, seen and unforeseen, at the time of forecasting profit. Under these circumstances, it is better to divide the profit reporting period on a half-yearly basis or at the most a quarterly basis (say in four to eight stages in the life of a project) using the following guidelines for adjusting profit:

S. No.	Profit reporting stages	Nature of forecast
(1)	Initial stage	Profit assessed at the time of tendering be reviewed, and profit forecast re-assessed and theoretical forecasts derived from 'S' curves be reduced, say about 20% to 25% at each progressive intermediate stage, up to half life of the project.
(2)	Intermediate stages	Compute actual profit, analyze reasons for variations and revise forecasts, if necessary.
(3)	Project completion stage	Profit is frozen after making provision for known and unknown expenses during the maintenance period and demobilization of site.
(4)	Final stage	Determine final net profit from the construction cost accounts after completion of maintenance period and demobilization from site.

It is worth noting that the profit computed in the cost accounting system (as outlined above) and the financial accounting system can differ. The differences mainly arise because of the following:

1. Some expenses appear in financial accounting but are not considered in cost accounting, e.g. discounts, profit on disposal of fixed assets, interest paid, fines and penalties and statutory expenses like income tax.
2. Differences may occur in pay back amount on account of amortisation and depreciation.
3. Differences may arise due to methods of valuation of stock inventory.

The difference in the profit and loss statement between cost accounting and financial accounting can be reconciled at the end of the accounting period and posted in the accounting ledgers through a 'memorandum of reconciliation' statement.

12.6.3   Forecasting Cash Flow

Despite the progressive payment stipulations in the contracts, the client as well as the contractors does face liquidity problems. Shortage of funds affects the progress of the project and in the worst case it can lead to stoppage of work. It is important that necessary capital budget provision be made well in advance to meet the inadequacy of the project cash requirements.

The project funding pattern can be determined by making a cash flow forecast that predicts the monthly net effect of the cash inflow and outflow. Separate cash flow forecasts are made by the client and the contractor. The purpose of the client's cash-flow study is to forecast the extent of the funds required periodically for meeting payment commitments. On the other hand, the contractor's cash flow forecast is more detailed and complex, as it has to cater for cash inflow as well as cash outflow.

While the contractor's cash inflow or project revenue receipts can be easily derived from the earned values budget, the difficulty arises in determining cash outflow. Some of the aspects, which need capital additions from time to time, are as given below:

• Working capital requirement;

- Major equipment purchase costs;
- Material inventory costs;
- Manpower mobilisation costs; and
- Temporary works and utility installations construction costs.

The detailed working of the month-wise cash outflow for each of the above items of expenditure is a tedious process. However, the cash outflow on account of the production expenditure can be determined with reasonable approximation by preparing a monthly schedule of expenditure after taking into consideration the anticipated deferred payment facilities and the paying of refunds spread over a long period in the form of retained profit/amortisation of long life fixed assets and depreciation of plant and equipment.

The difference between cash inflow and cash outflow, month-wise, gives the cash-flow pattern. The cumulative effect of the cash inflow and cash outflow, when plotted graphically against the project time, follows the 'S' curve pattern with the vertical difference between the two curves representing the cash resources status. For a long duration project the cash outflow will also have to be modified to cater to inflationary trends.

The negative cash flow experienced generally in the early stages of the project by the contractor calls for mobilisation of cash resources to meet the inadequacy of funds. The mode of financing can be divided into two categories, i.e. short-term and long-term financing. The sources of short-term financing include contributions from the owner's equity, overdraft and loan facilities from commercial banks, deferred payment facilities from the suppliers, and short-term borrowing from financial institutions against guarantees. The long-term sources of funds are retaining profits, rising share capital, bank loans, government loans, and loans from industrial and finance corporations. The extent of loan, which a contractor can muster, will depend upon many factors such as the financial position of the company, past performance of the company, project profitability, contractor's ability to provide guarantees, rate of payment of loans, and project cash-flow pattern.

Typical production-related cash flow cumulative graph.   A production-related cash flow statement forecasts the sources from which the funds are received and how it is utilised.
The parameters that enable preparation of the financial statement include the following:

V	=	Value of project workdone. It is the earned value of the workdone at the contract rate
C	=	Cost of production. It is the sum of direct materials, direct labour, direct other expenses and indirect costs.
R	=	Revenue. It is the amount received by the contractor on regular basis (generally every monthly) from the client for the value of workdone less deductions on account of retention for performance guarantee and advances made by the client as per contract. It is cash in flow.
E	=	Expenditure. It is equal to the payment made for the workdone and advances given for procurement of resources. It represents the cash outflow.
N	=	Net Cash Flow. It is the difference between the cash inflow and the cash outflow

Figure 12.4

Parameters for Preparation of the Financial Statement
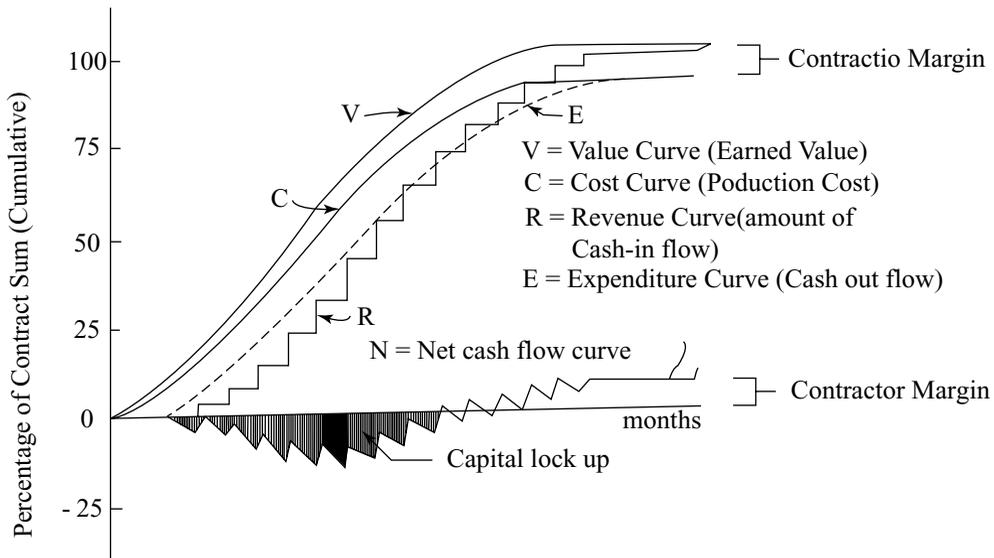
Example.   A residential building complex was contracted for a sum of Rs. 330 million. This lump-sum contract completion period was 12 months and the design and drawing formed part of the contract document. Contract was based on monthly payment of the value of work done to deduction of 10% retention refundable in one month after handing over of project. The contractors estimate was based on the following assumptions:

- Labour costs 20% of value of work, payment for 6 months, and the first of next month.
- Material cost 30% of value of work, payable after the month of receipt of revenue bill.
- Equipment cost 10% of the value of work, payable with beginning of the following month.
- General and Administration Expenses

The forecast of the cash flow can be evaluated as shown in **Table 12.7** and **Figure 12.5**.

12.6.4   Forecasting the Balance Sheet

A balance sheet shows what an organisation owns (assets) and what it owes (liabilities) during a certain period.

The project balance sheet is the statement of assets and liabilities of a project on a particular date usually, the end of the specified accounting period. Balance sheets are compiled for each accounting period. Besides showing the assets and liabilities, the balance sheets also provide a link between the successive accounting periods. According to statutory requirements, all companies have to produce an yearly balance sheet to show the capital invested and how it has been employed in the business.

Table 12.7)

Time (in months)

	1	2	3	4	5	6	7	8	9	10	11	12	13
Value of Work done Monthly	10	15	20	25	30	40	40	35	35	35	25	20	330
1. Cumulative value	10	25	45	70	100	140	180	215	250	285	310	330	330
2. Cumulative value less retention	9	22.5	40.5	63	90	126	162	193.5	225	256.5	279	297	297
3. Cumulative payment received from certification		9	22.5	40.5	63	90	126	162	193.5	225	256.5	279	297
4. Retention received													33
5. Cumulative cost (6) + (8) + (10) + (12)	7.5	18.75	33.75	52.5	75	105	135	161.25	187.5	213.75	232.5	247.5	247.5
6. Cumulative labour cost (20%)	2	5	9	14	20	28	36	43	50	57	62	66	66
7. Cumulative labour payment	2	5	9	14	20	28	36	43	50	57	62	66	66
8. Cumulative material cost (30%)	3	7.5	13.5	21	30	42	54	64.5	75	85.5	93	99	99
9. Cumulative material payment		3	7.5	13.5	21	30	42	54	64.5	75	85.5	93	99
10. Cumulative plant cost (10%)	1	2.5	4.5	7	10	14	18	21.5	25	28.5	31	33	33
11. Cumulative plant payment		1	2.5	4.5	7	10	14	18	21.5	25	28.5	31	33
12. Cumulative General and Adm. cost (15% variable plus fixed)	1.5 +3	3.75 +6	6.75 +9	10.5 +12	15 +15	21 +18	27 +21	32.25 +24	37.5 +27	42.75 +30	46.5 +33	49.5 +36	49.5
13. Cumulative General and Adm. payment	1.5	4.5	9.75	15.75	22.5	30	39	48	56.25	64.5	72.75	79.5	85.5
14. Cumulative cash out (7) + (9) + (11) + (13)	3.5	12.75	25.75	42.5	63	89	119	147.25	173.5	199.75	222.5	239.5	247.5
15. Cumulaive net cash flow (3) + (4) – (14)	-3.5	-3.75	-3.25	-2	0	1	7	14.75	20	25.25	34	39.5	82.5

Figure 12.5

Financial Parameters
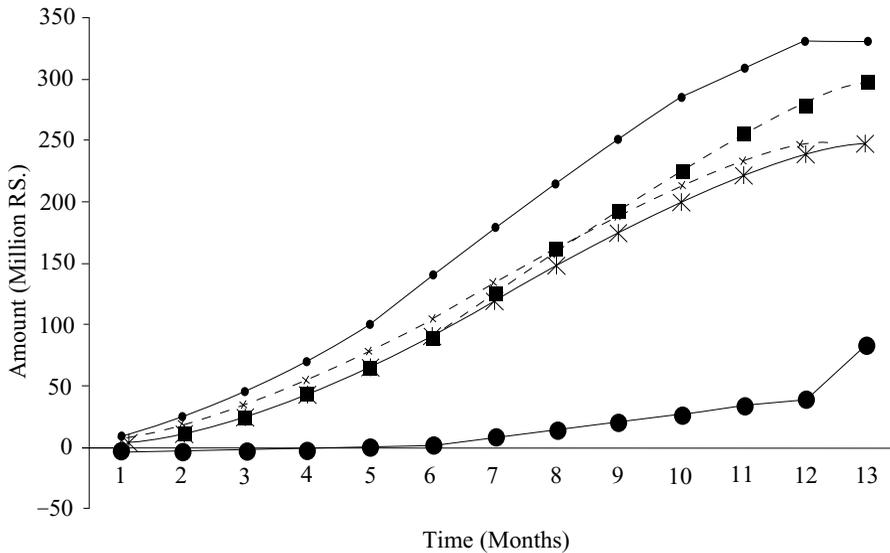
(Table Srial 1) ——•—— 1. Cumulative value
(Table Srial 3) – -■- – 3. Cumulative payment received after certification
(Table Srial 5) – -✳- – 5. Cumulative cost (6) + (8) + (10) + (12)
(Table Srial 14) ——✳—— 14. Cumulative Cash out (7) + (9) + (11) + (13)
(Table Srial 15) ——●—— 15. Cumulative Net cash flow (3) + (4) − (14)

Typical format of a balance sheet

Assets	xx	
Current assets Fixed assets	xx	
		xxx
Less liabilities		
Current	xx	
Long-term	xx	
		xxx
Shareholder's equity		xxx

Commonly used headings in balance sheets are standardized. These include the following:

(a) *Current assets*: These are sub-divided into debtors, (receivable) stock inventory, work in progress, short-term investments/advances and cash.
(b) *Fixed assets*: These cover land, building, plant and equipment, furniture and fixtures, all evaluated at their purchased value to the firm. Current value = Purchase value Depreciation.
(c) *Short-term liabilities*: These include the creditors to whom the money is payable for he goods and services supplied by them and the other sources from where the short term refundable funds are raised.

(d) *Long-term liabilities*: These consist of the loaned capital employed for running the project and employees' long-term benefit liabilities.

(e) *Shareholder's equity and surpluses*: These are contributions by the shareholders in the form of capital, stock, other assets and retained earnings.

The Project Balance Sheet forecast can be formatted as shown in **Table 12.8**.

Table 12.8

Balance Sheet Account

Assets	Liabilities and Capital Employed
Current Assets Cash in checking and savings accounts. Monies owned by customers (receivables). Inventory that can be sold immediately	**Current Liabilities** Monies owned to suppliers. Short-term bonds or other short-term debt.

Long-Long Term Assets
  Overdue receivables Loans to suppliers
  Investment in notes, real estate, other companies Plant and equipment Software (large value)
	Long-Term Liabilities
	Mortgages
	Long-term bonds
	Overdue payables

	Equity and surplus Cash paid in by investors for stock and retained earnings from operations and investments.

Notes:
 	
  Current assets are generally those assets that can be turned into cash within one year. Some companies may assign a shorter period.
  LLong-term assets are fixed assets acquired by the organisation for use over long period of time.
  The monetary value of all accounts of the left side must equal the value of the accounts on the right side.
	Notes:
	
	  Current liabilities are generally those due and payable within one year. Some companies may assign a shorter period.
	  Long-term liabilities are less liquid than current liabilities like loans payable after long term.
	  Equity is the monies paid in by owners surpluses are monies earned from operations and investments. These funds finance the assets of the business, along with the liabilities.

Note. The recent trend is to follow IFRS code for financial accounting and reporting purposes. This can be done by revising existing accounting standards to make them compatible with IFRS

❑ 12.7   ESSENTIAL FEATURES OF AN EFFECTIVE PROJECT MASTER BUDGET

12.7.1   Budget Manual

The project master budget integrates and summarizes the project functional budgets. At times, the master budget is also referred to as the finance budget or profit plan. The project master budget is prepared in the form of a manual. The text of a typical project budget manual may summarize the following. The detailed working patterns are attached as schedules or appendices with the text:

a. ***Project planned objectives***: These are stated in physical and financial terms with the plan assumptions and the functional organisation of work.

b. ***Organisation of responsibility centres***: It highlights the division of the functional organisation into responsibility centres (and their being further split up into work centres where applicable) with the tasks and resources assigned to each responsibility centre.

c. ***Earned values revenue budget***: It reflects the monthly or quarterly financial targets for the overall project and its breakdown for each production centre and other revenue earning sources.

d. ***Production cost budget***: It covers the production cost of goods sold, and it can be further split up into direct costs and indirect costs. These costs can be suitably arranged so as to bring out the production cost budget for each responsibility centre.

e. ***Project general and administration expense budget***: It represents the overall site office, administration, and head office expense budget, arranged in conformity with the finance heads of accounts and the functional needs.

f. ***Budgeted financial forecasts***: These include the profit and loss statement, cash flow forecast and forecast balance sheet.

12.7.2 Project Budget Preparation Guidelines

Budget preparation guidelines given below can go a long way to make a budget effective:

a. The budget should be prepared after the project plan is crystallised. A financial budget document compiled at the time of quoting a tender, however detailed, can at best be termed as 'preliminary budget'.

b. The budget should be prepared by a team and not by an individual, however efficient he may be. Specially, the preparation must not be left only to the accountants. Effective participation by the executives and heads of functional departments should be encouraged and ensured. This will safeguard the budget from becoming a mere paper-work exercise.

c. The budget should be prepared, proceeding systematically using scientific techniques as applied in a given situation, and it should not be viewed merely as a mathematical, statistical or accounting exercise.

d. The budget should be prepared in the format used for making a corporate budget, as far as possible, so that it can fit into the corporate financial accounting system.

e. Budget should be prepared as a comprehensive total document. Piecemeal budgeting should be avoided as this can result in imbalance if not carefully integrated into the overall budget.

f. The budget should be prepared keeping in mind that it has to be used for budgetary control. It is therefore necessary that a budget should specify the tools for measuring performances, and preferably incorporate the outline of the reporting system.

Numerous problems are encountered while preparing a budget. In the fast changing environment, it is difficult to forecast earned values. The production resource costs change frequently with the market trends. Future resource prices get affected with inflation but the earned value, which is based on agreed bill of quantities, remains the same. There is the behavioural aspect to budgeting. It includes

the tendency to inflate expenditure, and resistance to budgeting itself as the budget provides a tool to measure their performance.

It may be noted that the project budget can crash if it has unrealistic targets especially when it is thrust by the top hierarchy. A project budget is a financial plan based on certain assumptions and like the project plan, it needs to be reviewed regularly as it cannot take care of all eventualities and unforeseen circumstances. Further, a project budget provides a tool for effective management but it has to be handled carefully with the changing situations.

12.7.3 Importance of Project Budget

The project budget is essentially a planning document. It outlines the financial plan of the project. The project budget depicts the management's vision for the future. It aims at specifying the future financial course of action for steering the project. Budget quantifies in monetary terms the project cost objectives, it allocates responsibility for attaining these objectives, it reflects the resources earmarked, and it pinpoints the results to be achieved. It provides a standard for measuring effectiveness and efficiency with which activities are to be performed.

A project budget is a financial commitment for actions, an instrument for delegation of responsibility, a means for communication, an aid for coordination, a tool for motivation, an authority for implementation and a device for controlling performance.

A project without a budget is like a missile without a guidance system or a ship without navigational instruments. If there is no budget, there will be no means to measure performance. Working without quantified objectives and without commitments amounts to working aimlessly.

Budget and budgetary controls are inseparable. Without a budget, there can be no budgetary controls and without budgetary controls, even the best formulated budget will serve no purpose. Budgetary controls make use of budget and budgetary reports to compare the actual with budgeted standards to bring out the extent of variations, reasons out the causes for significant variations, bring out actions necessary to achieve objectives and provide a base for its revision when necessary. Budgetary controls methodology is described in **Chapter 15**.

APPENDIX L

Capital Investment Appraisal Techniques

❏ L.1   INTRODUCTION AND SCOPE

A project involves the current outlay (or current and future outlays) of funds with the expectation of getting future benefits. While capital expenditure decisions are extremely important, they also pose difficulties. Capital expenditure decisions involve substantial investment. Due to the inherent uncertainty, future predictions become difficult. It is difficult to identify and measure the costs and benefits of a capital expenditure since they are spread out over a long period of time, usually 10–20 years for industrial projects and 20–50 years for infrastructure projects. Capital expenditure decisions are irreversible; a wrong capital investment decision often cannot be reversed without incurring a substantial cost. Capital investment decisions have an enormous bearing on the future of an organisation. Capital budgetary proposals, therefore, demand a conscious approach in the early stages of the project formulation.

Capital investment analysis is the process of analysing the financial benefits of acquiring a capital asset with a view to determine the viability of the capital assets. It is a complex process as it takes into consideration depreciation, taxes and cash flow. This appendix outlines the methodology of the capital investment analysis in a non-commercial construction projects. The capital investment analysis involves the following steps:

1. Estimating the cash flow
2. Establishing the cost of capital
3. Applying the investment appraisal criterion
4. Conducting sesntivity analysis

❏ L.2   ESTIMATING CASH FLOW

L.2.1 Cash Flow Components.   These components in the product lifecycle costing can be divided into an initial investment, operating cash flows and a terminal cash flow:

1. **Initial investment**. It represents the relevant cash outflow or the cost of setting up the project.

> Initial investment = Cost of capital assets
>   + Installation costs
>   + Working capital margin

+ Preliminary and pre-operative expenses

– Tax benefit on capital assets, where applicable

2. **Operating Cash Flows**. These are the relevant cash inflows and outflows resulting from the operation of the project during its economic life.

Operating cash inflow in a given year = Profit after tax + Depreciation + Other non-cash charges + Interest on long-term debt – Tax rebate

3. **Terminal Cash Inflow**. It is the relevant cash inflow occurring at the end of the product life-cycle on account of project liquidation.

Terminal cash inflow = Post-tax proceeds from the sale of capital assets
+ Net recovery of working capital margin
+ tax adjustment, where applicable

L.2.2 Time Period Considered for Analysis. It is the minimum of the following:

- **Physical life of the project or plant**. It refers to the number of years the project or plant would perform the function for which it has been acquired.
- **Technological life of the project or plant**. It refers to the period after which the present the project or plant would become obsolete.
- **Product market life**. It refers to the period for which the product of the project or plant enjoys a reasonably satisfactory market.
- **Investment planning horizon of the firm**. It is the time period which a firm wishes to consider for investment analysis. It varies with the complexity and size of the investment. For small investments (say, the installation of a pumping set) it may be five years; for medium sized investments (say, purchasing a bulldozer or installing a readymix concrete plant), it may be ten years, and for large-sized investments (say, setting up of a new pre-cast concrete factory) it may be fifteen years.

❑ L.3 ESTABLISHING THE COST OF CAPITAL

This involves establishing the risk adjusted weighted cost of capital for the organisation. The capital for this purpose includes equity (share capital and retained earnings) and long term debt (loans, bonds). The cost of equity is the returns shareholders expect from the industry adjusted for the specific circumstances of the individual company. The cost of debt is the after tax effective rate of interest. The cost of capital for a company is the weighted average cost of equity and debt.

Example: Company A has equity and debt in the ratio of 60%–40%. The cost of equity for the company is 15% of the pre-tax and interest rate of long term debt is 9%. Tax rate is 33%. After-tax interest rate is 9% × 67% = 6%. With equity of 60% and debt of 40% and after-tax cost of 15% and 6%

respectively, the weighed average cost of capital = 15% × 0.6 + 6% × 0.4 = 11.4%

❑ L.4 APPLYING THE INVESTMENT APPRAISAL CRITERION

After the capital costs and cash flows are computed, the next step is to analyse the financial worthiness of the investment proposal. There are many methods for analysing investment proposals for making financial decisions. The commonly-used decision criterion can be divided into two broad categories, i.e. discounting criterion and non-discounting criterion.

a. *Discounting criterion*. These are based on net present value, internal rate of return techniques and cost-benefit analysis.
b. *Non-discounting criterion*. In this category, payback period is the commonly-used technique.

Net Present Value (NPV). It is the total of the present values of all the cash flows, out and in, over the product/plant lifecycle. The NPV is calculated as follows:

$$\text{NPV} = \text{PV of cash flows} - \text{Investment}$$

Notes:

1. The expected future net cash flows (inflows – outflows) are discounted at the cost of capital (r) to the base year (present time) to obtain the present value (PV) of these flows. Therefore, it is assumed that all future proceeds can be invested by the organisation at the cost of capital.
2. The initial cost of the investment (1) is subtracted from the present value (PV) to obtain the net present value (NPV) of the investment.
3. If the cost of the investment is spread over more than one year, the future cost must also be discounted at the cost of capital to the base year.
4. Calculation of the Net Present Value (NPV) is accomplished using the following formula:

$$\text{NPV} = \sum_{t=1}^{t=n} \text{NCF}/(1+r)^n - \text{Investment}$$

$$\text{NPV} = \frac{\text{NCF}_1}{(1+r)} + \frac{\text{NCF}_2}{(1+r)^2} + \frac{\text{NCF}_3}{(1+r)^3} + \cdots \frac{\text{NCF}_n}{(1+r)^n} - \text{Investment}$$

Where,
   NCF_1, NCF_2, NCF_3, … NCFn are the net cash flows (NCF) for the respective years;
   r is the cost of capital; and
   n is the expected life of the project.
An organisation should accept projects with a positive NPV and reject projects with a negative NPV.

Internal Rate of Return (IRR). It is the interest rate or discount rate, which gives zero Net Present Value (NPV) of investment over the project/plant lifecycle. IRR (r) is calculated using the following formula:

$$0 = \frac{\text{NCF}_1}{(1+r)} + \frac{\text{NCF}_2}{(1+r)^2} + \frac{\text{NCF}_3}{(1+r)^3} + \cdots \frac{\text{NCF}_n}{(1+r)^n} - \text{Investment}$$

where all the terms have the same definitions as those used in the NPV method.

IRR can be found using trial and error using PV tables. In the IRR method, it is assumed that all the future proceeds can be invested at the IRR rate. An organisation can accept a project that exceeds its cost of capital and reject those projects with IRR below its cost of capital. Projects with higher IRR can be preferred over lower IRR projects.

Pay-back Period. It is the time (in years) that a project/plant takes to pay back the initial cost of investment from the expected future net cash flows resulting from the investment. In other wordsit is the time during which the cumulative cash inflows equal to the original cash outflow. In this method, a cut off number of years can also be used to select or reject the investment proposal. Projects/Plants with shorter pay-back periods is preferred to those with longer pay-back periods. The pay-back period method does not take into consideration the time value of money and as such can lead to incorrect results. Its appeal lies is its simplicity in calculation and understanding and is particularly useful when there is low confidence in the magnitude of cashflows in the longer term periods. It is often used to supplement investment appraisal techniques of NPV and IRR for management decision making.

Benefit-Cost Ratio. It is the ratio of the present value of benefits to the initial investment. In other words, it measures the NPV per rupee of outlay.

> BCR = Present Value of benefits/Initial investment
> If BCR > 1, accept the proposal
> If BCR < 1, reject the proposal
> If BCR = 1, consider other factors for decision

Summary of Decision Criterion

Factors	Acceptance Criterion
Pay-back Period (PBP)	< Target period
Net Present Value (NPV)	> 0
Internal Rate of Return (IRR)	> Cost of capital
Benefit-Cost ratio (BCR)	> 1

Example: A reputed industrialist is considering a proposal to set up a block-making factory on his plot located in the industrial area. Initially he proposes to run this factory for four years and sell off the land and plant thereafter. For making the investment decision, the industrialist wants to know the NPV, IRR, pay–back period and Benefit-Cost ratio. The forecast of the cash flows is given in **Table L.3**.

Net Present Value of Cash Inflow on Investment

$$NPV = \frac{NCF_1}{(1+r)} + \frac{NCF_2}{(1+r)^2} + \frac{NCF_3}{(1+r)^3} + \cdots \frac{NCF_n}{(1+r)^n} - \text{Investment}$$

NPV in lakhs = $24.87 \times 0.909 + 43.86 \times 0.826 + 45.87 \times 0.751 + 55.05 \times 0.683 - 99.00$

$$= 130.88 - 99.00$$
$$= 31.88$$

Internal Rate of Return (IRR). The interest rate or discount rate, which gives zero IRR (r) is calculated using the following formula:

$$0 = \frac{NCF_1}{(1+r)} + \frac{NCF_2}{(1+r)^2} + \frac{NCF_3}{(1+r)^3} + \cdots \frac{NCF_n}{(1+r)^n} - \text{Investment}$$

$$0 = 24.87/(1+r) + 43.86/(1+r)^2 + 45.87/(1+r)^3 + 55.05/(1+r)^4 - 99$$

By trial using statistical table, $r = 22\%$.

Pay-back Period. It is the time (in years) that a project/plant takes to pay back the initial cost of

Table L.3

Cash Flow Forecast

(Rs. in Lakhs)

Years	0	1	2	3	4
A. Building and preliminaries	50.00				
B. Plant and equipment	44.00				
C. Working capital margin	05.00				
D. Revenue		209.95	279.45	279.45	279.45
E. Annual operating costs		137.44	181.47	181.47	181.47
F. Depreciation		5.68	5.68	5.68	5.68
G. Interest on short-term bank borrowings		14.04	11.03	8.02	5.01
H. General administrative cost		24.00	24.00	24.00	24.00
I. Total cost of sale (E + F + G + H)		181.16	222.18	219.17	216.16
J. Profit before tax (D – I)		28.79	56.27	60.28	63.29
K. Tax (Assessed)		9.60	19.09	20.09	21.10
L. Net profit after tax		19.19	38.18	40.19	42.19
M. Sale value of plant and equipment after 4 years					12.18
N. Net recovery working capital Margin					(05.00)
O. Initial investment (A + B + C)	(99.00)				
P. Operating cash inflows (L + F)		24.87	43.86	45.87	47.87
Q. Terminal cash flow (M + N)					7.18
R. Net cash flow (O + P + Q)	(99.00)	24.87	43.86	45.87	55.05
S. Discounted rate	10%				

the investment from the expected future net cash flows resulting from the investment.

$$99 = 24.87 + 43.86 + x\ 45.87$$

Payback Period = First year + Second year + (99 – 24.87 – 43.86)/45.87 of Third year
= 2.66 years

Benefit-Cost Ratio = Present Value of benefits/Initial investment
= 130.88/99
= 1.32

❑ L.5 CONDUCTING SENSITIVITY ANALYSIS

Sensitivity Analysis is a modeling technique used to determine the impact of uncertainties which are significant for the project. It helps to understand how the variation in one or more parameters correlates with the base values of others. It aids in determining the variables, which have the most potential impact in the project. It helps to understand how the achievement of project objectives correlates to the variation in different uncertainties.

L.5.1 Sensitivity in Economic Analysis

For viability result of financial/economic analysis (NPV, B/C, IRR) with respect to various variables/parameters, the sensitivity can be estimated. The variables considered may be:

- Project implementation time;
- Capital cost;
- Operating cost;
- Quantities and prices of outputs;
- Quantities and prices of inputs;
- Quantities of major work item;
- Taxes and duties;
- The discounting rate (cost of capital); and
- Any other important variable.

In economical sensitivity analysis, the viability result is calculated for different values of variable. For example, the the results of IRR calculated at different price levels may work out as under:

IRR at Normal price　　= 14%
IRR at 5% less price　　= 8%
IRR at 10% less price　　= 6%
IRR at 15% less price　　= 4%
IRR at 20% less price　　= 1%

From above, it is seen that the IRR is very sensitive to the price of the product. Therefore, it is important to estimate the price very realistically.

Take the case of the budget allocation. These are based on estimated cost. These costs are sensitive to changes in the parameters. The sensitivity analysis indicates the implications of changes. In simple terms, sensitivity analysis deal with the impact of change of the estimated cost/budget/investment with respect to the parameters. The Sensitivity Analysis becomes a complex process when a number of parameter changes are done simultaneously.

L.5.2   Sensitivity Analysis in Project Management

Sensitivity Analysis can determine as to how the the uncertainties affect each project objective. A tornado diagram bar chart can be used in sensitivity analysis for comparing relative importance of the variables i.e. Y-axis contain each type of uncertainty at base value and X-axis shows the horizontal bar chart spread in descending order.To quote a simple example, the tornado bar chart of a Housing Project showing Schedule Sensitivity Index, derived using Primavera Risk Analysis (see **Appendix Q**), is shown in the figure below:
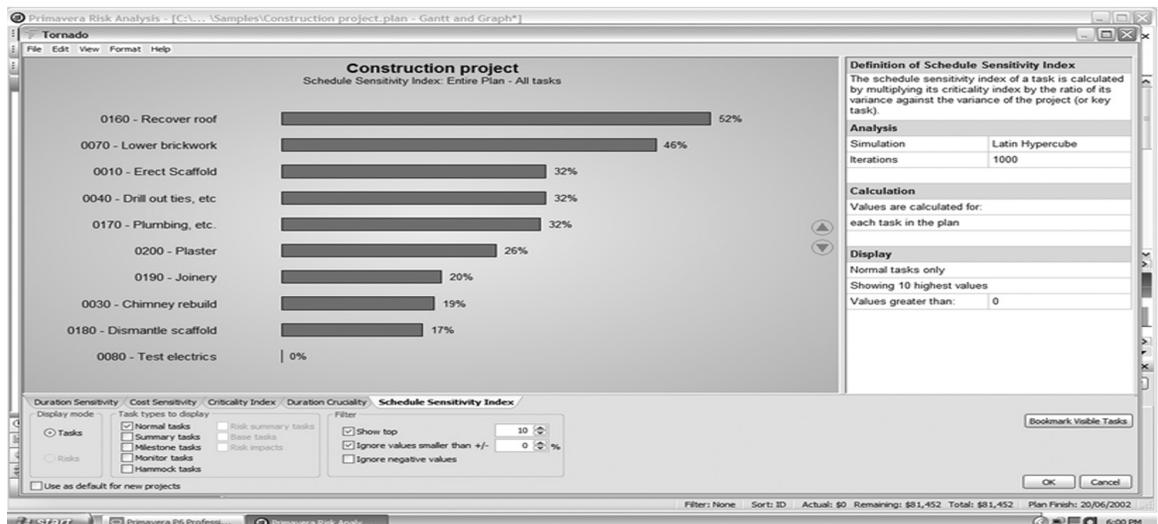
	Range			**NPV**		
Key Variable	**Pessimistic**	**Expected**	**Optimistic**	**Pessimistic**	**Expected**	**Optimistic**
Investment	26.4	22	19.8	−0.72	2.86	4.64
Sales	16.5	19.8	23.1	−1.29	2.86	7.04
Variable costs as percentage of sales	77	73.33	71.5	0.37	2.86	4.10
Fixed costs	1.43	1.1	0.88	1.62	2.86	3.66

(Rs. in millions)

L.5.3 Sensitivity Analysis Merits and Shortcomings

The Sensitivity Analysis has certain merits:

1. It shows how vulnerable a project is to changes in values of the variable parameters.
2. It indicates where further analysis is required. For example, if the NPV is highly sensitive to changes in some factor, it may be worthwhile to explore how the variability of that critical factor may be contained.
3. It is intuitively very appealing to the project evaluators.

But it has several shortcomings:

1. It merely shows what happens to investment when there is change in some variable, without indicating how likely that change will be.
2. Typically, in sensitivity analysis one variable is changed at time, however, variables tend to alter together.
3. The interpretation of results is subjective. One decision maker may decide to accept the project while another may reject it.

Controlling Project Integration and Work Scope

An efficient integrated project control system uses project management integrated plan to indentify, unify, coordinate and control the various processes and project management activities. It generates information that can improve the productivity of men and materials; economies the employment of resources; enable understanding of time and cost behaviour; provide early warning signals of ensuing dangers; update resource planning and costing norms; prevent pilferages and frauds; and assist in formulating bonus/incentive schemes for motivating people. Like the guidance system of a missile, a project needs an effective control system to continuously monitor the deviations from planned paths, and to apply corrective measures.

Work Scope Control aims at ensuring that the project includes all the works conforming to stipulated WBS, design, drawings, specifications and BOQ, and is concerned only with the authorised works required to complete the project successfully. The project's scope of work is not merely a work quantity and cost control exercise. It is carried out as per approved construction specifications and practices with the end product meeting the functional and specified requirements with workers working under safe, hazard free, and protected environment, keeping the delivery in pace with the integrated scope attributes and plans. Construction Workers Safety Measures are outlined in **Chapter 14**. Work Scope Control process is a sub-set of the project integrated control system.

This chapter outlines the project control methodology for controlling a time-bound, capital- intensive, high-cost construction project. It introduces the control system framework and identifies the parameters to be controlled for achieving specified objectives. Towards the end, it highlights pre-requisites for an effective control system. This chapter is divided into the following sections:

1. Project Integrated Control System Framework
2. Work Scope Control Methodology
3. Product Quality Control Methodology
4. Product Quality Cost/Benefit Analysis
5. Total Project Management versus Total Quality Management

6. Pre-Requisites of an Effective Work Scope Integrated Control System

Construction works are generally executed through contracts. **Appendix M** to this chapter outlines 'Construction Contract Administration and Claims Settlement Mechanism:

The methodology for resource productivity control; cost control and time control are described in **Chapters 14–16** respectively. Construction workers' safety measures are outlined in **Chapter 14**. Project Management Information System (PMIS) is in **Chapter 18**.

The contents of this chapter should be viewed as guidelines. The system and methodology covered here should be suitably modified to conform to the varied nature of the construction projects, and to meet the needs of the client and corporate management.

❑ 13.1 PROJECT INTEGRATED CONTROL SYSTEM FRAMEWORK

13.1.1 Systems Approach

A system is a set of interrelated elements that work collectively to achieve common objectives. It is an assemblage or a combination of things or parts forming a complex or unitary whole. The system approach is viewed as a series of logical, interrelated /processes that integrate all the necessary functions to achieve optimum performance.

Project integrated control follows the systems concept. Each organisational unit in a project usually referred to as a responsibility centre, can be viewed as a sub-system. These sub-systems are interdependent and interactive. Project control system is headed by a project monitor. Typical sub-systems encountered in a Housing Project are depicted in **Exhibit 13.1**. The project control system processes the actual performance accounting data generated by the sub-systems to extract and communicate information.

The project control centre, manned by a monitor, is the heart of the system. The monitor processes the performance data received from the sub-systems. Monitoring involves tapping of reported data from various accounting sub-systems (i.e. responsibility centres), consolidating and analysing this data to extract information suggesting remedial course of action for achieving project objectives. This information, when communicated at appropriate levels for making decisions results in steering the organisational efforts towards the attainment of the project objectives.

Steps in the integrated control process are as under:

Step 1. Define the parameters to be controlled;

Step 2. Establish baselines for measuring performance;

Step 3. Account performance feedback data by:

- Measuring performance,
- Recording performance, and
- Reporting performance deviations.

Step 4. Monitor performances by:

Project Control System

Project Control System
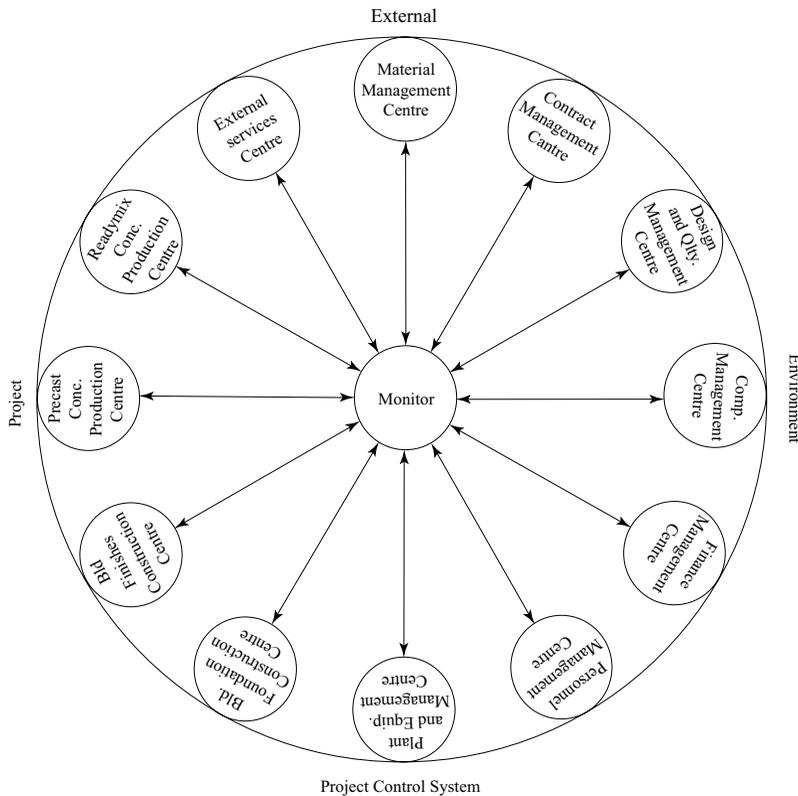
- Consolidating reported performance feedback data;
- Analysing performance variations; and
- Forecasting performance trends.

Step 5. Communicate information; and

Step 6. Keeping data records up-to-date.

13.1.2 Performance Parameters to be Controlled

Performance in simple words implies the degree of achievement. The performance goals of a sub-system are stated in terms of parameters to be controlled. The typical parameters include time-progress targets, resources productivity standards, project earned value, and standard costs. Each sub-system accounts for its performance and transmits the deviations between the planned and the actual performance to the monitor. The schematic diagram of a parameter control process is shown in **Figure 13.1**.

Figure 13.1

Schematic Diagram of Performance Control Process

Remedial Action Decisions

| Responsibility Centres | → Performance Data Input → | Project Monitoring Centre | → Information → | Management Decisions |

Output

Feedback
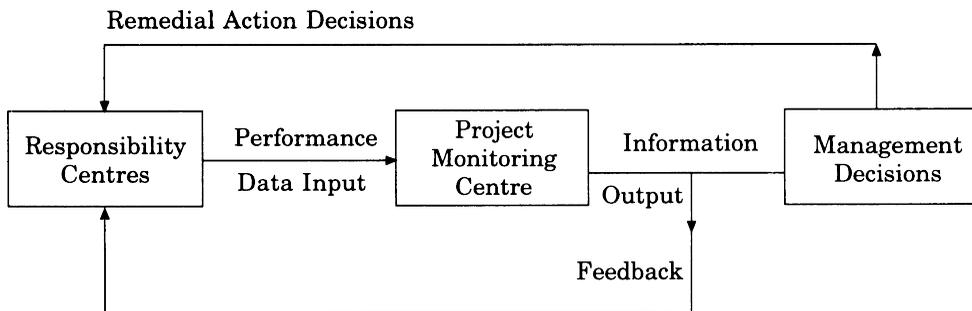
In a construction project, the typical parameters that may be controlled are as follows:

a. **Work Scope Control**: It aims at ensuring that the project includes all the works conforming to stipulated design, drawings, specifications and BOQ, and is concerned only with the work required to complete the project successfully. Work scope control ensures that only authorised works are done. These works are carried out as per approved construction practice, while working under safe environment and the end product meeting the functional and specified requirements. It involves:

- Measuring the approved work scope progress including ordered work deviations.
- Analysing the implications of deviation from the sanctioned work in terms of quantity of work, completion time and resources required and cost involved.
- Formulating remedial measures.

Work Scope Control methodology is covered in the later sections of this chapter.

b. **Time progress control**: It aims at the timely execution of the work as per the work programme and applying corrective measures in case of deviation so as to achieve the project time objective. It involves:

- Measuring the project time progress;
- Analysing the implications of deviation from the project time schedule; and
- Formulating remedial measures including time crashing to achieve project time objectives.

Time Control methodology is covered in **Chapter 16**.

c. **Resource procurement management**: It aims at ensuring timely availability of resources at the site as per requirement. Resources forecast guidelines are covered in **Chapters 7–10**. The following aspects are reviewed during the review meetings:

- Updating the resource status and forecasting requirements.

- Analysing the implications of variations from the original mobilisation plan.
- Directing resource mobilisation for timely completion.

d. **Resource productivity control**: It aims at effective utilisation of direct resources of man, materials, plant and machinery and involves the following.

- Evaluating variances from resource productivity standards.
- Analysing the causes of variations.
- Directing resource productivity improvement measures.
- Revising resource standards (if necessary).
- Modifying resources mobilisation plan (if necessary).

Resource productivity control methodology is covered in **Chapter 14**.

e. **Production direct cost control**: It aims at economising operations by creating cost-consciousness in the project environment and involves the following.

- Analysing causes for variances;
- Directing cost economising measures;
- Developing unit rates of items of work for future tendering; and
- Updating project cost status.

Direct Cost Control methodology is covered in **Chapter 15**.

f. **Earned value control**: It aims at forecasting cost performance trends from the budgeted cost plan by and involves the following:

- Evaluating project cost status and its variations from the budget.
- Analysing causes for variations.
- Forecasting production costs behaviour.
- Initiating cost reduction measures.

Cost and performance control methodology is covered in **Chapter 15**.

The parameters required to be controlled, listed above, are indicative and not exhaustive. Depending upon the nature of the project, there can be additions and alterations in these parameters. For example, in a simple project, direct cost control can be combined with resource productivity control or budgeted cost control. In complex projects, new parameters such as investment (portfolio) control may have to be added to evaluate the economics of 'make or buy' and 'hire or purchase' decisions. Further, in case of projects being executed in a foreign country, mobilisation control becomes necessary so as to ensure the timely induction of resources.

The control parameters are not mutually exclusive. They are interrelated as well as interdependent (see **Figure 13.2**). To quote an example, the work-progress time goals do get affected if the productivity adopted norms change or the resources are not inducted as per mobilisation plan. Similarly, the budget is interlinked with the outcome of almost all other parameters. The weaknesses and deviations in each of these parameters resulting from non-fulfillment of planned targets, not only have their repercussions on the respective parameter goals but these affect the project as a whole.

Figure 13.2

Project Performance Control
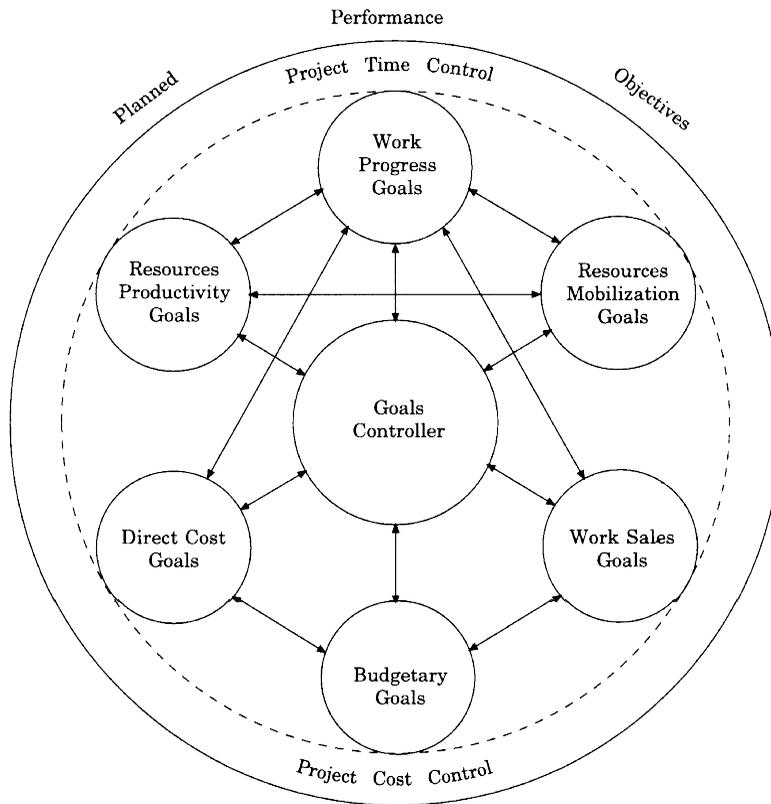
Performance

Interaction and interdependence of performance goals.

13.1.3 Performance Baselines

Performance is measured with respect to predetermined specified targets or standards termed as performance baselines. These baselines are devices used for measuring performance variations by comparing the originally planned performance with the actual performance to determine the deviations from the planned path. The purpose of establishing performance baselines is to assist the responsibility centres in measuring deviations in the actual performance from the planned standards. It is these deviations that serve as the early warning signals of ensuing dangers to the goal controllers.

In a typical project, the baselines for controlling parameters of scope, time, resources and cost objectives are tabulated as in **Table 13.1**.

It may be noted that the baseline or standard performance parameter of a work package are fixed (or frozen) till it is revised during the course of implementation of the project. These baselines are an assessment of the expected performance by the planners. It may not be equal to the performance

Table 13.1

Controlling Scope, Times, Resources and Cost Performance Baselines

S. No	Control Parameters	Performance Baselines
1	Project work scope	Forecast time phased quantities of work and earned value
2.	Time progress	Project master-time schedule
3.	Resources productivity	Resources performance standards
4.	Resources mobilisation	Project resources induction plan
5.	Work package direct cost	Direct cost standards or budget
6.	Work done revenue	Forecast cash flow
7.	Project cost	Project budget
8.	Quality of the product	Product design, drawings and specifications

estimated by the estimators at the time of tendering. An important point to remember is that a given task can be executed by different methods, but the actual performance is based on the method actually adopted for execution and how efficiently it was performed, and not on what was considered at the time of estimation. These performance baselines should be reviewed after 20%–25% of the project has progressed.

13.1.4   Performance Accounting Process

The term 'accounting' covers measuring and recording actual performance, and reporting it to the appropriate authority. The accounting methodology depends upon the parameters being controlled.

Measuring and Recording Performance: Performance is measured in relation to the baseline yard-stick. Recording involves documenting facts about the actual progress of goals/targets/activities/resource using established procedures or specified devices, and presenting these facts in a concise and comprehensive form for analysis. The performance measured is documented systematically. The recording of performance by a contractor at the project site can be divided into two groups, i.e. recording in contractual documents and recording in contractor's own accounting documents.

Project contractual documents.   These documents are maintained jointly by the client and contractor at the site to record the work progress, resource employment, and other progress related matters. In large-size projects, the contractor furnishes this information to the client in the form of reports. The client's engineer, after scrutiny, gives his remarks on the documents at the specified places. The types of documents vary from client to client and project to project. Some of the commonly used contractual documents for recording work related matters are listed below:

- Work schedule and work programmes;
- Work diary;
- Stage passing register;
- Work deviations order register;
- Work measurement books;
- Work progress reports;
- Materials sample approval register;
- Materials inspection registers;
- Major equipment employment register;
- Equipment instruments calibration certificates;
- Equipment performance test report;
- Contract cost status; and
- Minutes of site meetings.

In particular, it is a usual practice to maintain a works diary to daily record the weather, activities in progress, manpower engaged at the site, major materials received, equipments deployed, important events of the day, and the name of the project related visitors. This document is scrutinised daily and signed by the client's engineer with his remarks and is kept with the client. Contractual documents are primarily used by the client to monitor the contractor's work progress, but these are not sufficient for the contractor to control his time, resources and cost objectives.

Contractor's documents.   At the project site, the contractors design their own systems for accounting the project parameters. Generally, their functional heads maintain their project records centrally, but the physical performance data originates from the respective responsibility centres. Accordingly, each responsibility centre also maintains its respective documents (hard or soft copies) to record the progress of the work and day-to-day employment of resources of man, materials and equipment. In addition to the work-package performance monitoring sheet, some of the documents used on the construction site for recording performance data are listed in **Table 13.2**.

Reporting performance by responsibility centres.   A performance report is generally a written document that shows the up-to-date performance status of a task entrusted to a responsibility/accounting centre. Performance reports transmit the performance data covering the actual achievements and deviations from standards, and highlight the reasons for such deviations in a standard format at a predetermined frequency to the specified monitoring centre. The frequency of reporting varies with the nature of the task being handled by the performance centre and the efforts required to compile it. The nature and frequency of these reports encountered in typical major housing construction projects are shown in **Exhibit 13.2**.

Guidelines for designing performance data reporting.   The desired input data can best be obtained by the monitor through suitably designed performance reports taking the following into consideration:

Table 13.2

Contractor's Documents for Recording Performance Data

S. No.	Control Parameter	Facts Recorded	Typical Recording Documents
(1)	Work progress	Actual starting and completion dates of each activity	Works diary, Daily work progress report, work-package performance sheet
(2)	Materials utilization	Receipts and issues	Materials ledgers
(3)	Manpower utilization	Daily workers' employment	Time-keeper's muster rolls register/sheet
(4)	Plant and machinery utilization.	Hours utilized	Equipment operation log-books
(5)	Production costs	Actual costs	Construction accounts
(6)	Earned Value	Quantity and value of work done	Measurement books Monthly invoices of work done and materials at site Extra work statements

1. What are the short-term goals and long-term objectives assigned to the Responsibility Centre?
2. What is the data needed to monitor the performance of these goals and objectives?
3. How should this data be obtained from the initiators, viz. in a verbal or a written form?
4. What should be the nature, format and frequency of reports to be submitted by each control responsibility centre to the monitor?
5. Is the data reported required for controlling the performance of other control centres?
6. If so, who should be asked to initiate the report?
7. How accurate should each report be? The degree of accuracy will depend upon the purpose of the report.
8. Will the report initiator need additional assistance to submit the report? If so, what and how much? (In particular, the stationery and printing requirements should also be assessed.)
9. Can the report under consideration be eliminated, substituted, combined, rearranged or simplified? This should be re-examined before finalisation.

It is emphasised that there are no tailor-made formats for reporting performance. Generally, the contents of a report should show the performance goals in the form of current and cumulative status. It should indicate variances from planned targets with reasons. It should identify bottlenecks in achieving goals and it should highlight the aspects that need further action.

The reporting formats should conform to the monitor's specifications, organisation's management information system (MIS), computer software requirements, and codification system. The format design should seek the participation of the performance controllers prior to finalisation.

In particular, responsibility centres must not be loaded with paperwork. The reports should be

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Exhibit 13.2

2000 Housing Units Project: Typical Responsibility Centre Control Performance Report

</div>

S. No.	Responsibility Centre Designation	Purpose of Report
Central Batching Plant		
1.	Monthly concreting materials reconciliation report	(a) To assess wastage of materials.
		(b) To take stock of materials
2.	Daily concrete production and delivery report	(a) To monitor the daily performance of the concrete production centre
		(b) To determine excess concrete consumed building-wise and activity-wise
Rebar Yard		
3.	Daily reinforcement fabrication report	To assess daily output for cutting, bending and transportation.
4.	Weekly materials reconciliation report	(a) To assess wastage of materials
		(b) To evaluate total fabrication work done
Construction Sites		
5.	Activity-wise progress report	To monitor daily physical and financial progress activity-wise
6.	Labour Employment Report	(a) To assess manpower output activity-wise
		(b) To control effectiveness of machines employment
Plant and Equipment Maintenance Centre		
7.	Machinery utilisation report	To monitor performance of machinery
	Materials Department Reports	
8.	Daily cement, sand and aggrega te. Receipt report	To record quantity of cement, sand and aggregate received from various sources
9.	Daily imported materials and machinery received	To monitor mobilisation of materials and implication of the deviations from laid down stock levels
10.	Weekly status of important construction materials	To monitor procurement status

Personnel Department Reports

11.	Workers, daily employment report	To control employment of workers within the project
12.	Workers arrival/departure report	To update manpower planning and distribution records
13.	Weekly site staff allocation report	To control overall distribution of key project personnel

Technical Department Reports-Design and Drawings

| 14. | Approval of drawing status | To monitor the schedule of approval of drawings |

Quantity Survey Section

15.	Weekly status of quantities estimates.	To monitor the progress made in estimation of quantities.
16.	Weekly materials sample approved status	To track the materials procurement plan
17.	Monthly value of work executed	To monitor the value of the work done/earned value

Planning Cell

18.	Weekly work progress materials monitoring report	To analyse the implications of deviations from the project plan
19.	Weekly resource mobilisation monitoring report	To forecast changes in resources requirements
20.	Monthly site report	As per the requirement of the client
21.	Monthly management information report	To report performance and hold-ups/ bottlenecks to corporate management

designed in such a manner that it reduces the recording effort. To quote an example, the 'daily activities time progress' report format of the foundation responsibility centre of the housing units project is shown in **Exhibit 13.3**.

This report served the following main purposes:

a. It made the site supervisors pre-plan for the next day's work including the allocation of resources for each activity.

b. It provided the following valuable data to the monitor and cost accountant in respect of each current activity:

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Exhibit 13.3

Foundation Construction Sub-project Daily Progress Report: Communicated Orally

</div>

S. No.	Activities per Module	Unit	Quantity	Modules Completion Reported Earlier	Foundation Tasks Building Nos.		
					Completed Previous Day	In Progress Today	Planned Next Day
1.	Layout for excavation	-	-				
2.	Excavation with machine	CM	400				
3.	Base preparation	SM	360				
4.	Anti-termite at base	SM	362				
5.	Polythene sheeting	SM	362				
6.	Shuttering for blinding	RM	90				
7.	Placing concrete M-100	CM	18				
8.	Layout for raft	-	-				
9.	Shuttering for raft	SM	22.5				
10.	Reinforcement for raft	MT	6.066				
11.	Raft concreting M-250	CM	88.14				
12.	Curing raft	-	-				
13.	Bitumen coating raft sides	SM	362				
14.	Layout for plinth wall	-	-				
15.	Wall shuttering	SM	485				
16.	Wall concreting M-250	CM	43.78				
17.	Deshuttering	-	-				
18.	Curing wall	-	-				
19.	Bitumen coating wall and raft	SM	319				
20.	Back filling	CM	120				
21.	Plinth filling	CM	05				
22.	Anti-termite under GF slab	SM	172				
23.	Polythene sheeting	SM	225				
24.	Shuttering for GF slab	SM	11				
25.	Weld mesh fixing	MT	0.651				
26.	GF concreting M-250	CM	28.34				
27.	Curing GF slab	-	-				

- State of time progress showing the dates of commencement and completion activity-wise;
- Correlation of activity with resources deployed and consumed such as man-days utilised for the completion of each activity and the corresponding productivity achieved;
- The earned value of the work done; and
- Reasons for hold-ups or work stoppages.

When read with the time-keeper/foreman's activity-wise daily workers' employment report (see **Table 14.3**), the monitor can determine the workers' productivity in man-hours consumed for each completed activity. Further, by suitably designing the Demand and Delivery Note, the monitor can assess the wet concrete wastage for each concreting activity by comparing the actual concrete supplied with the theoretical quantity, after he receives the daily building-wise concrete delivery report from the ready-mix concrete centre.

Similarly, by comparing the ready-mix concrete responsibility centre's monthly stock consumed and concrete supplied report, the monitor can estimate the percentage wastage of cement, sand and aggregate. The format given in **Table 13.3** will prove useful.

13.1.5 Monitoring Performance

The performance monitoring process commences after the monitor receives the appropriate performance data through site reports, personal visits and discussions. The performance monitoring processes include consolidation of reported performance data, analysis performance variances and forecasting of performance trends.

Consolidating data.   The responsibility centres' performance reports generate ample tabulated data. This reported tabulated data, generally unorganised, needs consolidation and reorganisation. The common types of charts used for control data consolidation can be divided into the following categories:

a. *Network charts:* These are used for controlling of project time schedule. Examples are CPM, PERT, precedence network diagrams, and time-scaled network charts.
b. *Tables:* These are used to compile and compare data such as in financial statements and work-progress evaluation.
c. *XY charts*. These indicate trends over a period of time. There are many varieties in the XY charts.

Types	Examples
XY Bar charts	Bar chart schedules
XY Line charts	Resource productivity control charts
XY Curve charts	'S' Curve forecasts. Cyclographs

The main types of XY charts considered useful for consolidating data are listed in **Table 13.4**. Consolidated data displays in the form of graphs, charts, diagrams, tables and pictures have visual appeal. They are the best means of human communication. Visual displays help in understanding

Table 13.3

Batching Plant: Materials Wastage Control Report Summary
Ready-mix Concrete Monthly Stock Status

		Cement	Sand	Aggregate
(A)	Opening stock	x	xx	xxx
(B)	Quantity received	xx	xxx	xxxx
(C)	Closing stock	– (x)	– (x)	– (xx)
(D)	Actual amount consumed (A + B – C)	xx	xxx	xxxx
(E)	Budgeted consumption for			
	concrete supplied	xx	xxx	xxxx
	Wastage (E – D)	x	x	x

the complications and interrelated states of performance of various control centres at a glance and provide insights into the operations.

Analysing performance variances. The term 'variance' stands for the difference between the planned and the actual. When associated with the parameter of a work-item or activity being controlled, variances represent differences in planned and actual performance of the controlled factors.

$$\text{Performance variance} = \text{Planned performance} - \text{Actual performance}$$

For example,

$$\text{Work quantity variance} = \text{Planned work quantity} - \text{Actual work quantity}$$
$$\text{Activity duration variance} = \text{Planned activity duration} - \text{Actual activity duration Production cost}$$
$$\text{variance} = \text{Standard production cost} - \text{Actual production cost}$$
$$\text{Sales revenue variance} = \text{Budgeted value of sales revenue} - \text{Actual revenue from sales}$$

Variances when evaluated can be zero, plus or minus. Plus or zero value variances are called favourable, and the minus value variances are termed unfavourable.

$$\text{Variance} > 0, \text{Favourable (F)}$$
$$\text{Variance} < 0, \text{Unfavourable (U)}$$

To quote an example, if the actual cost of a work-item is greater than the standard cost, the work-item has an unfavourable variance.

Further, a variance is said to be controllable if it is associated with the operational efficiency, say the responsibility of an executive or the performance of a work-centre. For example, variance due to wastage of concreting material more than the planned wastage is a controllable variance.

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Table 13.4

**Typical XY Charts for Data Consolidation
(Prepared Manually Or Using Software)**

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S. No.	Type of charts	Application	Example
1.	XY Horizontal bar	To show growth trend with time.	Work schedules
2.	XY Stack bar	To demonstrate parts of a total, spread over a time period.	Month-wise workers forecast
3.	XY Stack bar cumulative	To depict increase over a time period in numbers or percentage.	Financial cumulative forecast month-wise
4.	XY Paired bar (horizontal or vertical)	To compare planned and actual.	Double bar charts
5.	XY Curves	To highlight changes in data over time.	Cumulative 'S' curves
6.	XY Line (zigzag)	To illustrate sharp changes in trends.	Resources productivity charts
7.	XY Deviation (line or bar)	To compare changes from the standards.	Range charts
8.	XY Point chart	To establish correlation.	Concrete wastage chart
9.	XY Histograms	To depict frequency or probability distribution.	Risk probability distribution pattern

On the other hand, the causes of variance which are beyond the control of the management such as increase in labour wages due to labour legislation are called uncontrollable variances.

The primary purpose of introducing the variance concept is that it generates information for determining the causes of deviations from the planned approach. Variance analysis generally follows the questioning approach following:

1. What is the extent of the variance?
2. What are the controllable and the uncontrollable causes of variances?
3. How to tackle controllable and uncontrollable variances and what are their implications?
4. Will the uncontrollable variance occur again? If so, when and what will be its effect?

It may be noted that variance analysis presupposes that the work-item or activity being analysed is identifiable and measurable and therefore, each variance can be considered an isolated item. But some of them may have interacting effects and in such cases they should be analysed in conjunction with others. An example of variance analysis of direct cost of a raft foundation is given in **Chapter 15**.

Trends forecasting. Performance variance analysis reveals the extent and causes of variances. On the other hand, performance efficiency, when read in conjunction with variance analysis, indicates the implications of the past performance on future trends.

Performance variance = Planned performance – Actual performance.

$$\text{Performance efficiency} = \frac{\text{Actual output performance}}{\text{Planned input performance}}$$

Performance efficiency (or index) determines how efficiently the task was done; performance efficiency greater than 1 shows better performance than planned and vice versa. See the following:

Performance efficiency > 1,   Performance better than planned
= 1,   Performance equal to planned
< 1,   Performance less than planned

Performance efficiency is a trend indicator. It provides the tool for forecasting future requirements of resources.

A simple method of forecasting trends is to calculate the performance efficiency and to proportionately increase or decrease the resources for the remaining work. For example, consider a masonry wall construction activity with planned and actual performance as follows:

	Planned Performance	**Actual Performance**
Scope of masonry work	1200 m²	1200 m²
Crew size	8 men	8 men
Construction time	15 days	18 days

Labour performance efficiency for the given task can be calculated as under:

Planned labour performance = 8 men × 15 days = 120 man-days
Actual labour performance = 8 men × 18 days = 144 man-days

$$\text{Labour performance efficiency} = \frac{\text{Work done per Man-day}}{\text{Work planned per Man-days}} = \frac{W/144}{W120} = \frac{120}{144} = \frac{5}{6}$$

Therefore, one of the approaches for determining the resources for future similar works to be completed during the specified period of 15 days (disregarding improvements in efficiency due to the learning process) is to increase the labour crew size in proportion to the recorded actual labour performance efficiency = 8 × 6/5, say 10 men.

This simple approach for forecasting future labour requirement trends based on performance efficiency is not enough. This performance efficiency should be studied along with performance variance to determine what caused the low performance and whether these causes will be repeated or not, and what is the possibility of improvement by adopting alternate construction methods, through better organisation or with the learning process, or a combination of all these factors (see 'Direct Cost' and 'Earned Value' analysis examples in **Chapter 15**).

Understanding of some of the techniques and concepts given below can help in producing a realistic forecast of future performance. There are no hard and fast rules to state as to which technique will be used, when and where:

a. *Time forecasting techniques.*
b. *Network analysis and line-of-balance technique.*
c. *Statistical analysis and operations research methods:* Data analysis, forecasting, regression analysis, statistical control charts (similar to statistical quality control) and analytical decisionmaking techniques.
d. *Management accounting technique:* Cost accounting, cost control, working capital management, cost-benefit analysis, break-even analysis, and performance audit.
e. *Management concepts:* Management principles, behavioural science, personnel management, materials management, plant management, finance management, contract management and quality management.

The method of controlling and forecasting the performance can be broadly divided into three categories, i.e. resource performance forecasting, time performance forecasting, and cost performance forecasting. Earned Value Analysis for defining cost parameters, evaluating variances, determining performance efficiency and forecasting trends on completion are described in **Chapter 15**.

Monitoring frequency. It is a debatable point as to what should be the frequency of performance monitoring. One school of thought lays stress on economising monitoring costs. Another school of thought advocates site reporting and monitoring at regular preplanned intervals of time. It is felt that depending upon the importance and complexity of the project, the status evaluation of controlled parameters should be carried out immediately on receipt of the concerned performance reports, whereas trend analysis from baselines can be performed at weekly/fortnightly/monthly intervals. Replanning is a time-and-effort consuming process and it should be undertaken only when necessary.

It is important to note that effective monitoring depends upon the accurate and timely reporting of the input data. Delays or distorted data lead to incorrect analyses. Similarly, monitoring has no meaning if the feedback by the monitor is not given on time to the site executives. Team spirit coupled with a sense of responsibility of all the participants can go a long way to make monitoring effective.

13.1.6 Information Communication

Information is the crucial ingredient of e decision-making process. Timely, relevant and accurate information is necessary for making quantitative analysis of feasible courses of action for achieving goals and deciding the most suitable one for implementation. The greater the size and complexity of the project, the greater is the need for information pertaining to the project resources and their performance behaviour within the framework of stipulations made in the project plan.

The project control system aims at economically collecting the right information in the right form through the right means at the right time from the right place and communicating it to the right person on time for taking the right action. The project monitor, who taps data from various sources and processes to extract information, is assigned the task of data record keeping, data processing and timely communication of the performance feedback to the project teams and the information report to the top management.

Data record keeping.   The project data bank, manned by the monitor, can be set up at each site to hold the following up-to-date records (soft and hard copies, as appropriate) for ready reference:

- Contract documents including terms and conditions, drawings, specifications, bill of quantities, and activity-wise costs and sale prices;
- Project models, layout pictures, tabulated scope and progress-of-work statements, and photographs depicting work progress;
- Project plans and connected charts, networks, planning assumptions including productivity standards;
- Statistics of various reports and returns handled in the project and pictorial displays;
- Records of minutes of all meetings, conferences, policies and important correspondence;
- Control charts showing progress-of-work, mobilisation status of resources, contract cost status and the 'S' curve forecasts; and
- Updated unit rates and resource cost planning data.

It is ideal to have a project control room at site office where all updated monitoring information is displayed. The executives should be encouraged to regularly visit this room and read the feedback.

Feedback communication.   Feedback conveys information to the responsibility centres pertaining to their performance and its implications on assigned goals. It may reveal what was achieved, what was targeted for accomplishment, what is the extent of deviation in performance, what caused these deviations and what are the remedial courses of action possible.

Feedback can be communicated in many ways. It can be transmitted verbally, in the form of brief feedback reports or as briefings during regular planning meetings. In these planning meetings the monitor can highlight the subsequent performance targets and the measures contemplated by the project manager. Where considered necessary, minutes of the formal planning meetings can be recorded and distributed to all concerned. As far as possible, writing lengthy memoranda and notes should be avoided.

It is important that feedback is given in time, as delayed feedback may not serve the purpose. For example, it is no use telling a site engineer a week after the completion of an activity that its productivity was 20% lower than the standard rate. Timely feedback creates prompt awareness and enables initiation of timely remedial actions.

With the right feedback, the site executives can analyse their performance and take remedial measures where necessary. In fact all executives need feedback to effect improvements. It is unfortunate that at some sites, executives rarely come to know of their performance because of lack of monitoring or non-appreciation of the importance of feedback. It may be noted that the monitor diagnoses the deviations and formulates remedial actions but he cannot implement these himself. It is the site executives who are responsible for processing the work as per project plan and correcting deviations from the planned path.

Project management information report.   The corporate management or the board of directors are primarily concerned with time and earned value progress, profitability, cash flow, and capital investment needed for achieving the objectives.

The contents of the project management information report will vary with the nature of the project and can be broadly divided into six parts as given below:

a. *Project particulars:* It shows the report title, number and date of report, project name, code number, location, client's details, and site address.
b. *Project objectives status:* It includes information relating to:

- Original contract amount, amount of work deviation, and percentage of financial progress.
- Contract starting date, current week numbers, balance of original completion period (in weeks), extended completion period (in weeks), total completion period (in weeks) and final completion date.
- Suspensions or hold ups during the reporting period.
- Client's extended completion date.
- Expected completion date as per current plan.

c. *Project parameters' performance status:* Performance of parameters to be reported depends upon corporate policy. The selected parameters can vary from a few like billing status, work progress and budget status to a detailed report on performance of targets of each responsibility centre.
d. *Project resources mobilisation forecasts for the next quarter:* It outlines the near-future resource requirements at the site for achieving planned targets. These forecasts include the following:

- Site staff status and forecast of requirements;
- Workers' status and forecast of requirements;
- Materials sample approval status;
- Major materials procurement status and scheduled requirements; and
- Equipment status and induction schedule for balance required.

e. *Gist of important site meetings:* These include meetings with client's representatives, subcontractors, suppliers and other connected agencies. It is in addition to the recorded minutes of meetings which are submitted to the top management.
f. *Concluding remarks:* The concluding paragraph of the report summarises the overall performance and highlights the actions requested from the top management.

In addition, up-to-date graphs showing the performance of selected parameters can be attached with the report.

The project management information report generally, does not include classified information such as controversial issues, actual expenditure details, profitability status, and financial matters. These are dealt with separately by functional managers.

The project report must be concise and meaningful. It should indicate variances from the planned targets with reasons. It should restrict the report to essentials, making the report exception oriented by focusing attention on critical areas. Its contents should contain more of statistics, graphs, charts and other details having visual appeal. Narration as far as possible should be kept to the minimum.

It should highlight potential bottlenecks and aspects needing action at the top-management level. It should avoid duplication of effort by suitably designing the reporting format to conform to the site reports, computer software requirements, and codification system.

❑ 13.2 WORK SCOPE CONTROL METHODOLOGY

Work scope control aims at ensuring that the project includes all the works conforming to stipulated WBS, design, drawings, specifications and BOQ, and is concerned only with the work required to complete the project successfully. Work scope control ensures that only authorised works are done. These works are carried out as per approved construction practices, under safe, hazard-free environment and the end product meets the functional and specified requirements. It involves:

- Measuring the approved work scope progress including ordered work deviations;
- Analysing the implications of deviation from the sanctioned work in terms of quantity of work, completion time, resources required and cost involved; and formulating remedial measures to accomplish the project; and
- Project close-up.

13.2.1 Work Scope Authorisation: Who Authorises Whom?

Authorisation stages. In construction projects, there are three stages in authorisation of works. These are project authorisation, contract works authorisation and execution of the construction activity at the project site.

Project authorisation. If the project is approved for implementation, the project scope formulation phase concludes with the documentation of the project charter or work operation order and the selection of the project manager. The project charter includes a statement of the broad functional scope of the construction work, its objectives, an outline execution methodology, milestone time-plan, major resource forecasts, cash flow forecast, outline organisation and potential risks and problem areas. The scope statement provides the justification for undertaking a project; it outlines the project purpose, features of the project product, broad scope of the work, and the project time, cost and quality objectives.

It is the project charter that authorises the client appointed project manager to go ahead with the project within the funds budgeted for each stage of work and constraints stipulated in the project charter. He resumes full responsibility for managing the project from concept to completion including concept development, selecting consultants, feasibility analysis, scope development, preliminary planning, budgeting costs, contracting and contract management, work execution and final close up.

Contract work authorisation. The two parties involved in the execution of work are the client and the contractor. Both have their OBS and the RAM to ensure that project is executed

efficiently, effectively and safely within the stipulated time, budgeted cost and the specified quality to meet the functional requirements set forth in the project charter.

The contract scope defines the works that must be undertaken in order to deliver a facility, a product or a service with the specified features and functions. These attributes and characteristics may include specified quantities, completion time, budgeted cost, and product quality specifications. Contract works can commence subject to terms and conditions stipulated in the contract with the approval of the client. Some of the conditions stipulated in the contract include submission by the contractor of documents listed in **Table 13.5**.

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Table 13.5

Submission by Contractor as per Contract-Stipulations

</div>

1	Construction works time schedule in Bar Chart and Time analysed networks submissions by contractor as per contract stipulations, supported with specified project management software, within the specified period of the award of the contract. (say 4 weeks)
2	Design and drawings approval schedule, and site survey and investigations, as applicable.
3	Construction equipment mobilisation plan supported with output calculations.
4	Schedule of Approval of material's samples.
5	Resources Mobilisation Plan month-wise to be submitted within specified days of approval of Program
6	Construction Method Statement confirming to technical specifications.
7	'S' Curve forecasting value of Work Done and forecast of cash flow.
8	Product Quality Management Manual.
9	Safety, health and environment protection plan, confirming to statutory regulations and site conditions, to be submitted within specified days of approval of Project time schedule.
10	Project organisation and responsibilities assignment chart.

It is the project manager (and his team) that manages contract work on behalf of the client and it is he who authorises the contractor to proceed with commencement of the work requested by contractor after verifying and approving the Construction Method Statement prior to commencement of the appropriate activity.

Method statement is a document that describes the systematic and orderly arrangement of executing a task/activity. The object of developing a post-tender stage method statement is to get work right the first time, avoid rework, execute the work efficiently, effectively and safely. The method statement prepared prior to execution of work enables sequencing work, optimising resources, and exercising supervision by filed supervisors. In case of disputes, it aids in settlement of claims.

The construction method statement is prepared by the contractor and approved by the client engineer-in-charge in advance of the commencement of construction activity/work/process such as excavation, formwork, rebar fixing, concreting work, hot-weather concreting, erection of girder in a structure etc. The construction method statement includes nature of work, relevant specifications,

good-for-construction drawing references, sequencing of work, workers earmarked category-wise with skilled workers certification/experience (specially in cases like welding, electrical work, pre-cast erection), construction material with sample approval references, the equipment to be employed. It may also include the name of the supervisor, duration/schedule of each operation, and the safety precautions to be observed.

13.2.2 Project Scope Change Control System

In the interest of the project purpose; the project scope may undergo some changes from the original scope of work. In case of changes, the necessary change control system must bring out the impact of change on project time, resource and cost objectives prior to the approval of its implementation. Such deviations in the scope of work, depending upon the source of origin can be broadly divided into two categories, i.e. owner requested changes and engineering warranted changes. All such changes have implications. All such (feasible) changes must therefore be well-considered and agreed upon by the client prior to implementation (except in the case of an emergency). The implications of the change, which must be considered, may include the effect on the planned time schedule, budgeted cost, resource mobilisation, design and specification, development methodology and the safety of workers. These changes must be authorised in writing, recorded in the change order register, distributed to all concerned and tracked till completion. A typical project scope change order is shown in **Table 13.6**. It must be ensured that no unauthorised work is undertaken, so as to avoid conflicts and disputes, at a later stage.

13.2.3 Project Close Up

Project closing is an important but often neglected phase of a project. A properly closed project after completion of scope of work is an invaluable asset to the organisation and stakeholders who participated in the accomplishment of the project. Client satisfaction on close up is necessary for future business promotion by the stakeholders. The project review on termination highlights lessons for improving organisational strategies and policies. The various reasons that lead to neglect in the closing phase of a project include insufficient time, extra effort, lack of enthusiasm after completion of the project etc. In case, where the project fails, the project team may have inhibitions about discussing the shortcomings that made it unsuccessful.

The main focus of the client's project team in closing up the project is to ensure that the project's product functions satisfactorily after it is handed over to the client. The team prepares a project manual which may include the project history, the important events, the scope and schedule of work, the salient features of the contract(s) executed, the addresses of the suppliers of materials and equipment, the equipment operations and maintenance manual, the as-built drawings and the final costs. It may also include the problems encountered during execution, the lessons learnt, the minor defects noticed at the time of handing over and post-completion maintenance requirements. In most cases, the contractor responsible for construction is given a one year maintenance responsibility after completion. This aspect is generally included in the scope of work of the contract. In addition,

Table 13.6

Sample Scope Variation Order (SVO)

Project Code and Title	SVO Number Issue date
Summary of change with justification and quality specification(attached sheets, if necessary) Originator: Date:	
Effect on Project Schedule (Attach justifications, where required):	
Effect on Resources and/or Cost (Attach detailed estimate, where required):	

Approved with following comments/not Approved
 	
                                        Client's authorised Manager:
                                                    signature	

Distribution:	

the staff and workers necessary for operating and maintaining the facility are trained prior to its taking over and the project is cleared of the remaining unwanted materials. The project team fully safeguards the client interest before making the final payments.

The contract and administrative close up by the project team include update of contract documents, performance measurements, final scope of the project with proper record of the product/service, acceptance certificates, operating instructions and as-built drawings and correspondence on outstanding disputes and claims. The project team also notifies the sellers and vendors about the project completion and may obtain a no-objection certificate from them. Finally, a ceremony may be held to mark the formal completion of the project.

❏ 13.3   PRODUCT QUALITY CONTROL METHODOLOGY

13.3.1   Quality Control

It involves monitoring output of specific stages in the production of facility to determine if they comply with relevant quality standards and identifying ways to eliminate causes of unsatisfactory results. Quality Control in a large sized project is performed by a fully equipped and staffed Quality Control Department or similarly titled organisational unit.

The quality control measures in a project include:

- Creating quality consciousness;
- Mobilising resources for assuring and controlling product quality;
- Setting up site material testing laboratory and establishing other sources for materials testing;
- Training the concerned staff;
- Implementing quality plan;
- Testing incoming and locally produced materials;
- Monitoring quality performance;
- Investigating cases relating to quality failure to prevent recurrence;
- Formulating plan for re-work when needed; and
- Feedback quality performance for effecting improvements.

13.3.2   Quality Inspection

Project scope is verified through inspections. Inspection determines the acceptability of a product or a service or stages of production. It includes activities such as measuring, examining, and testing undertaken to determine whether results conform to requirements. Inspections may be conducted at any level (e.g., a single activity or the final product of the project or statistical quality control methods).

Inspector's primary function is to make sure that the production complies with the specification document. In addition, the inspector anticipates the future errors and takes measures to prevent them. An inspector should never be satisfied with merely reporting mistakes in the work after they are made. Inspector can prevent problems by continually reviewing the specification documents, and personally visiting all stages of production. Timely inspection of the delivered materials can prevent rework and delays, if incorrect material gets incorporated into the work. It is an established fact that a competent inspector is worth many times its cost in preventing omissions of production and can jeopardise the safety and the structure of the project.

13.3.3   Product Rework

The work found defective/rejected after inspection for deviating from the technical specifications falls into two categories, i.e., repairable or totally rejected. The totally rejected non repairable work is dismantled/demolished and disposed off. The repairable work is subjected to rework. The rework is aimed at bringing a defective or non-conforming item into compliance with requirements or specifications. Rework results in extra costs and time delays and the cost arising out of poor quality of work may rise to as high as 30% of direct cost.

> ### Typical Rework Causes Breakdown
>
> - 46 % incorrect execution
>
>   – 30 % lack of care
>   – 8 % lack of information
>   – 4 % lack of competence
>   – 4 % lack of knowledge
>
> - 30 % failure in design and development
> - 8 % lack of clear data
> - 8 % material faults
> - 6 % impossible to execute
> - 2 % of others

It is important to note that quality must be built into the product from the early stages of the project development. An error in the design stage will have more impact on quality than, say a rework on defect rectification during production. For example, a design discrepancy in an RCC beam design, if noticed during pre-concreting stage will cost for redesigning and work stoppage but if observed after concreting, will cost for dismantling and recasting, and if it cracks after the building is occupied, then the cost of rectification will include cost of user's vacating premises/inconvenience and cost of rework of all the affected structural components. Conceptually, a design defect will cost n number of times for design rectification prior to production, not less than n2 times for rectification during the execution stage and for more than n2 times for rework during the operation/maintenance stage.

13.3.4 Quality Audit

A quality audit is a structured review of quality management activities. Its objective is to identify measures that can improve performance and quality of this project or that of other projects. Quality audit is necessary to simulate and maintain unending improvement in team performance and product quality. In particular, audit should focus at the project defined quality standards. Quality audits may be scheduled or random, and they may be carried out by properly trained inhouse auditors or by registered third parties such as quality system agencies. Also see **Chapter 17**.

13.3.5 Quality Control Tools and Techniques

Quality Control tools and techniques identify and separate the causes of quality problems and solve these in precise language that can be understood by all the concerned team members (see **Figure 13.3**). Commonly used traditional quality control tools and techniques are tabulated (**Table 13.7**). The QC tools provide both a graphical and measured representation of processed data. These basic tools are Data Tables, Histogram, Pareto analysis, Cost-and-Effect analysis, Trend Analysis, Scatter

Figure 13.3

Quality Control—Traditional Techniques

Problems Identification   Problem Analysis

• Data Collection & Consolidation

• Pareto Analysis

• Cause & Effect Analysis

• Trend Analysis

• Histograms

• Scatter Diagrams

• Control Charts
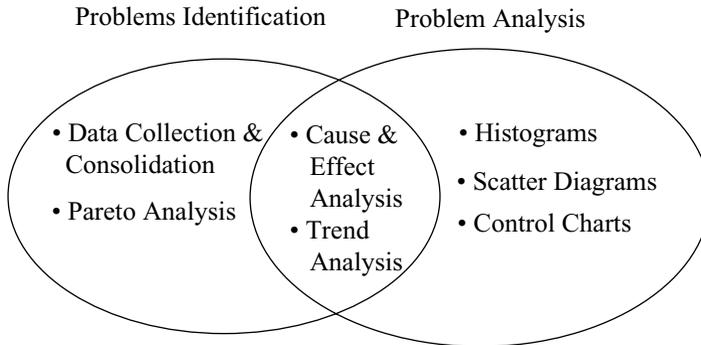
Table 13.7

Quality Related Problem Solving Tools and Techniques

	Tools and Techniques	Purpose
1.	Brain storming	To generate tolls problem solving techniques ideas for solving a problem
2.	Histogram	To consolidated data graphically
3.	Data collection and analysis	To consolidated data in tabular form/tally sheets to get an overall picture
4.	Pareto diagram	To sort data using 20/80 rule for identifying vital issues
5.	Control charts	To determine deviations from the desired level of performance
6.	Caused and effect	To establish relationship for identifying censes for observed effect/problem.
7.	Scatter diagram	To establish relationship between causes

Diagram and Process Control Chart. These basic tools provide for the efficient collection of data, identification of patterns in the data, and measurement of variability. Statistics makes the decision making more objective.

The statistical methods result in the following benefits:

- Improved process information
- Better communication
- Discussion based on facts
- Consensus for action
- Information for process changes and decision making.

Advance problem solving tools can contribute as below:

- Bench marking. Its purpose is to compare with the industry best practices with a view to enhance performance.
- Matrix data analysis. It displays and analyse multi-dimensional grid type data.
- Tree diagram analysis. It can analyse the best strategy for accomplishing an objective.
- Risk analysis. It facilitates forecasting and planning risks arising from unforeseen situations.

13.3.6 Work Scope Functional Verification Prior to Acceptance

Purpose and process.   Work scope verification prior to acceptance serves a two-fold purpose. Firstly, it aims to ensure that the project includes all the works required with specified attributes and characteristics, and that only the work required to complete the project successfully is undertaken. Secondly, it verifies the deliverables prior to acceptance in order to ensure that they conform to specified functional requirements. Verification focuses on ensuring that:

- Only the works assigned are undertaken for implementation.
- Execution of work is properly managed to conform to design, drawings and specifications.
- Quantities of work variations are analysed.
- Completed works are verified to ensure that they meet the requirements.
- Scope change control is regulated for addition and alteration in the scope of work.

Essential requirements for verification of a deliverable.   An inspector assigned the responsibility of verification must:

- Study contract documents before commencement of the work and request clarification for all items not fully understood from the people concerned.
- Organise a recording system for documenting performance.
- Obtain a complete set of contract documents and all codes and standards governing the work and manufacturer's literature.
- Generally be acquainted with and have access to reference standards.
- Be familiar with codes applicable to the work and seek interpretation if in doubt.
- Establish procedures for communications, correspondence, shop drawings, samples, substitutions, payments, changes, tests, and specialised inspection.
- Understand and possess a Work Scope Integrated Plan and a schedule of values for progress payment evaluation.

The role of the inspector verifying and certifying acceptance.   It includes the following:

1. Looking ahead of the work being performed so as to anticipate items that might tend to interfere with the progress of the project.

2. Conducting inspections of the work in progress to determine compliance with the specified requirements.
3. Ensuring that no unauthorised work is executed and extra work does not commence until a change order is issued, or necessary instructions are given in writing by the appropriate authorities.
4. Recording deficiencies observed on relevant documents.
5. Obtaining project manager's interpretation or decision on all matters needing clarification.
6. Verifying that the testing laboratory performs all tests and conforms to the nature of the tests required. He must also review the test conducted and seek clarifications on observed deficiencies.
7. Evaluating variances between actual progress and planned/estimated progress. He must record and report circumstances that may cause a delay in completion of the work.
8. Keeping an accurate daily record of labour, materials and equipment being used for additional work ordered with the contractor.
9. Recording situations that warrant raising of claims on the contractor and report to the person concerned.
10. Not allowing deviations from the contract documents until approved.
11. Not interfering with the work to be performed by the contractor or advising him on issues related to any aspect of methods, techniques, sequences, procedures or assuming any responsibility for the performance of his work.
12. Not stopping the work on his own without written authority from the owner or project manager.
13. Being able to affirm and certify in writing that in his best judgment the works executed conform to the stipulated requirements.

13.3.7 Main Benefits of Product Quality Control Measures

Implementation of Product Quality Control has many advantages. It safeguards customer requirements, defines organisational roles and responsibilities and authority of major functionaries. It controls quality of all operations, activities, materials and service providers like vendors and subcontractors. It increases efficiency and productivity, improved confidence and pride in the organisation mission and continues upgradation of knowledge and skills of personnel.

❑ 13.4 PRODUCT QUALITY COST BENEFIT ANALYSIS

13.4.1 Quality Costs Involved

The primary cost of meeting quality requirements is the expense associated with the quality management activities. These quality costs can be divided into control costs and failure costs. Control costs are made up of preventive costs and appraisal costs, and the failure costs include internal failure costs and external failure costs.

$$\text{Quality cost} = \text{Control costs} + \text{Failure costs}$$
$$\text{Control costs} = \text{Prevention costs} + \text{Appraisal costs}$$
$$\text{Failure cost} = \text{Internal failure costs} + \text{External failure costs}$$

13.4.2 Preventive Costs

These are the costs arising from the quality related activities required to eliminate negative deviations from the conformance specifications. These costs include:

- Quality planning
- Design review, Capability analysis, Process controland Quality audit
- Cooperation with subcontractors
- Establishment and maintenance of quality system
- Training in inspection/control system

13.4.3 Appraisal costs

These costs comprise of expenses incurred to determine whether a product, process or service conforms to specified requirements or not. Examples of appraisal costs are :

- Incoming and in-process inspection and tests.
- Final inspection, quality analysis
- Procurement and calibration of testing/ measuring equipment
- Vendor evaluation
- Product quality audit

13.4.4 Failure Costs

Failure costs are those resulting from non-adherence to specifications. These can be divided into internal failure costs and external failure costs. Examples of these are:

Internal Failure Costs.   Cost of reworking on defective products.

- Cost of failure analysis
- Wastage of resources in defective rectification
- Cost of unnecessary repetition of activities
- Idle time/wasted time/ scrap accumulation
- Re-inspection and correction of reworked products

External Failure Costs.   Cost of defects found after receipt of product by the customer.

- Warranty claims
- Customers/Clients conflict arising from complaints and their response

- Cost of returned products and their replacements
- Loss of goodwill/image
- Loss of customers

13.4.5   Cost Benefit Model

In a typical project, the prevention/appraisal costs and cost of failure are inversely related, i.e., when prevention cost increases the failure cost decreases and vice versa. However, there is a point where the total cost is the lowest (optimum) see **Figure 13.4**.

Figure 13.4

Cost Benefit Model
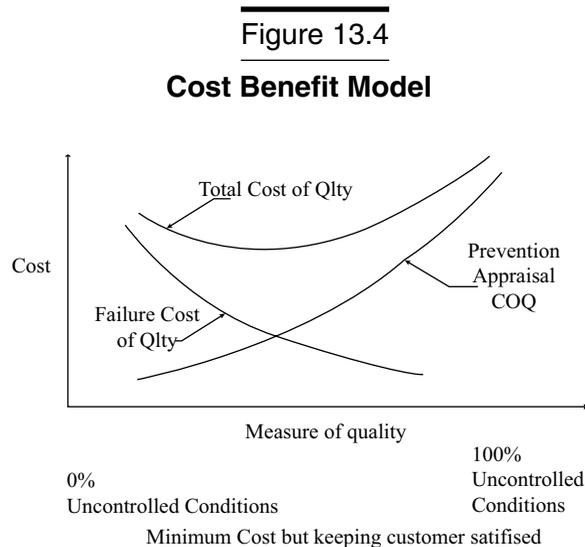
Considering the above, in the initial stages, the cost of controlling quality (prevention and appraisal costs) at near zero-defect is higher than the cost of failures under uncontrolled conditions. However, as the work progresses, the number of failures fall due to better management of quality, the need for appraisal and control declines, thus reducing the project life-cycle cost. Eventually, with better management, the total cost of quality becomes lesser than it was at the start, even though the cost of prevention initially was higher.

   Better quality management has also certain indirect benefits. Examples of these benefits include a satisfied customer and on the other hand, loss of business of an unhappy customer; the improved productivity of a satisfied employee and the lost productivity of a dissatisfied employee. Ultimately, it is the corporate that benefits from the quality work produced at the project site and in the long run the quality management benefits outweigh the initial costs incurred. But it should be remembered that cost of quality should match with the product quality requirements, since a customer may not like to pay for extra features which he may not require.

❑ 13.5   TOTAL PROJECT MANAGEMENT VERSUS TOTAL QUALITY MANAGEMENT

13.5.1   Total Quality Management (TQM) Philosophy

Total Quality Management (TQM), the buzzword of the 1980s, has now resurfaced again with the ISO 1900:2000. TQM has rightly been called as a quality revolution in the industrial sector. Evolution of TQM started with inspection, followed by Quality Circles and Control (QC), Quality Assurance (QA) and then TQM. TQM has been viewed differently by various organisations and thinkers. Some of the ways in which TQM is defined are as under:

- TQM is an approach to put quality in every aspect of management;
- TQM means that everyone in the organisation is involved in the final product or service to the customer. Quality means conformance to requirements;
- TQM is a strategic, long-term set of practices that make it possible for management to introduce continuous improvement initiatives across all functions; and
- TQM is a set of philosophies by which management systems can direct efficient achievement of the objectives of an organisation to ensure customer satisfaction and maximise stakeholder value.

TQM has two facets, i.e. the human side and the system component. In short, TQM focus is on quality, based on the participation of all its members and aiming at long-term success through customer satisfaction, with benefits to all members of the organisation and the society. TQM is a continuous process for improving quality of the product.

Crosby, Deming, Feigenbaum, Ishikawa and Juran can be considered most important gurus of the quality management movement. A brief comparison of the ideas of these quality gurus in relation to the TQM dimension show common threads and differences. It can be seen that the need of top management support and the importance of customer relationship is shared by all. Deming and Crosby focus their approache in the production process without reference to the design process. Crosby advocated the achievement of zero defects through employee commitment, whereas Deming criticises slogans and exhortations to achieve zero defect. Ishikawa's approach is more employee focused than the other four, which considers that quality management needs to be guided mainly by managers. Juran, Ishikawa and Feigenbaum have emphasised the need for sampling inspection, whereas Deming criticises this technique and Crosby considers that it is not necessary in a zero-defect environment.

In the global market, a number of companies are applying TQM. The criteria for the Malcolm Baldrige National Quality Award in USA for a total quality managed company include the company's performance on:

- The leadership role of the senior executive.
- The company's strategic planning.
- The customer and the market focus.

- The use of information to support key company processes.
- HRD and utilisation of full potential of the work force.
- Management of processes to achieve better performance.
- The Company's better performance related to competitiveness.

In this millennium, TQM appears to be a well-accepted system of management. There are differences in the definition and application of TQM amongst different authors and countries. Since the culture of the company influences the approach to the application of TQM, different countries with different cultures apply TQM in different ways. However, with the passage of time these differences are bound to diminish.

13.5.2 TPM Scope

The two key aspects in the Total Project Management (TPM) are the quality of the delivered product/services and the quality of the project management process. The ISO 10006: 97 'Guidelines to Quality in Project Management' identifies ten groups of project management quality related processes. These project management processes relate to management of scope, time, resources, costs, procurement, human resource, communication, risk and integration (see **Figure 13.5**). These are in addition to the General Management processes and practices, as covered in business management schools. Thus Total Project Management (TPM) covers technical management plus project management plus business management (general management areas) disciplines.

Total Project Management = Technical Management + Project Management + Business Manageent

13.5.3 TPM vs. TQM

The emerging 'Total Project Management (TPM)', also called the Modern Project Management, has similarities as well as differences with the TQM philosophy.
Similarities: In the project context, TPM as well as TQM implies total active involvement and commitment of everyone in the project for meeting quality requirements of the clients, by managing the production efficiently through preventive measures within the specified time and budget cost, with all working enthusiastically as a team to achieve specified targets to meet customer satisfaction. Both TQM and TPM focus on customer satisfaction, the process management, the management responsibility for creating an environment for quality, and continually improving process.

Differences: TPM and TQM concepts have some differences. TQM is a strategic approach to create a quality focussed culture in an organisation for long-term gains whereas TPM uses cross-functional and multidisciplinary project teams using tactical approach to manage product quality, and project management processes to attain project stakeholders' satisfaction. TQM provides a long term vision of how to achieve the best to satisfy the present and future customers; while the art and science of TPM focuses on planning, scheduling, monitoring and controlling, with the active participation of the stakeholders and the project team, to ensure that the vision is accomplished within the project specified completion period, in a cost-effective manner client satisfaction. TPM

Figure 13.5

Total Project Management Model
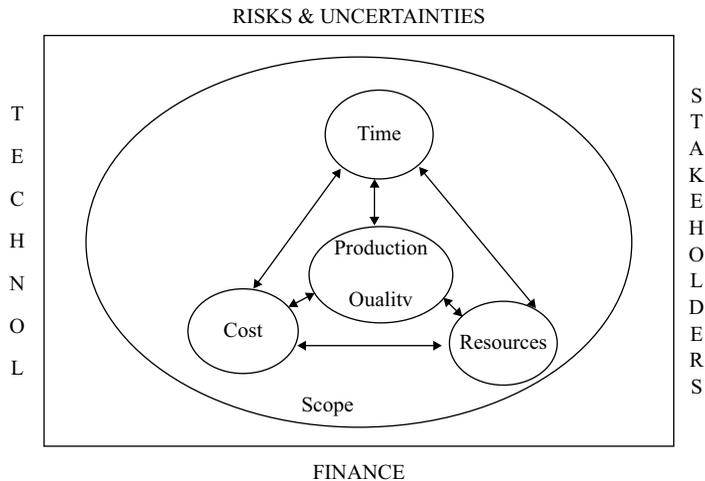
is a service that delivers a new product, whereas TQM focus is on the manufacturing industry mostly dealing with the ongoing product. TQM aims at continuous improvement of the product in the long run whereas project is designed to accomplish its mission within a limited time in a temporary organisation.

❑ 13.6 PRE-REQUISITES OF AN EFFECTIVE WORK SCOPE INTEGRATED CONTROL SYSTEM

Experience shows that the controlling systems are rarely implemented effectively at the project sites despite the well-recognised import ance of controlling projects. There could be many reasons for this slipshod attitude to the system. The inherent variables in the construction project make it impossible to derive a tailor-made solution for developing and implementing a project control system. Further, managers and site engineers are generally hesitant to face predetermined performance evaluation measures specified in control systems. A control system involves interaction among managers and the system collapses when there are conflicts and communication gaps. It is noticed that in the initial stages, project management continues to debate the design and procedure of the control system and in turn, the implementation continues to slip, thus resulting in e loss of valuable time and information.

Policy and methodology. The problems and conflicts inherent in controlling projects can be minimised if the management has a clearly defined policy on how to organise a control system and each participant understands its methodology. Project control can be said to be effective if the management:

- Implements efficient control procedures and systems.
- Develops and updates the estimates.
- Analyses trends to discover potential problems and takes remedial measure.
- Encourages a cost-conscious and time-conscious attitude.
- Continuously examines methods of execution with the objective of anticipating and reducing project time and cost over-runs.

For effective implementation, a project control system should be easy to understand and simple to implement, and as far as possible it should not create any interdepartmental and interpersonal conflicts. The system should have the least response time, thus enabling quick monitoring and prompt decisions based on simple reports. Numerous types of project management softwares are available in the market, but there is no system that can suit projects of all types and sizes.

Plan back-up.   The effectiveness of the project control system, to a great extent, depends upon the foundation on which the system is built. As a prerequisite, the system must be backed up with a realistic organisation structure, time, manpower, materials, machinery, mobilisation and cost plans of the project.

Control responsibilities.   Control is a personalised activity as all control functions are exercised through people. Knowledge, ability and motivational skills may differ from person to person. Behavioural scientists have brought out abundant literature on control theory. However, it is an established principle that no one can be held responsible for an activity, over which he has no control. For example, in the execution of a construction activity at the site, a construction supervisor is responsible for materials consumed. He cannot be asked to account for the price of materials incorporated into the work, as it is the materials manager who has to account for these prices. Efficient and effective achievement of goals depends upon the contribution of persons controlling the goals. In order to make the system effective, it is imperative that in a control system, the accounting responsibilities of persons at each control point be clearly defined. In particular, the management must clearly define the role and responsibility of the project manager and the planning chief.

A typical performance control responsibility matrix showing the project control responsibilities of various managers is given in **Exhibit 13.4**.

Exhibit 13.4

**Typical Performance Control Responsibility Matrix
for a Medium-size Housing Project**

S. No.	Control Responsibility	Time Control	Resources Control	Cost Control
1.	Design Manager	Timely supply of drawings	Drawing effort and project laboratory	Design costs
2.	Construction Manager	Time targets and Milestones	Resources productivity, safety and forecasting resources	Work package/Activity direct cost and earned value
3.	Contract Manager	Contract time and works quantity estimates	Variations from original works	Earned value and extra works claims
4.	Plant Manager	Timely supply of equipment	Plant and equipment maintenance and utilisation productivity	Plant and equipment operation costs
5.	Materials Manager	Timely supply of materials	Materials procurement safety and security	Materials costs
6.	Personnel Manager	Timely provisioning of manpower	Manpower mobilization, welfare and security	Manpower indirect costs and project administration costs
7.	Finance Manager	Provisioning funds	Resources budget	Cash-flow, expenses and budgeted costs, budgetary control
8	Directional Control by Project Manager assisted by Planning, Cost, Finance and Contract Manager for scope control	Project time objectives	Resources performance and mobilization	Cost and Performance/ Profitability control

APPENDIX M

Construction Contracts Administration and Claims Settlement Mechanism: An Overview

❑ M.1 INTRODUCTION

Construction contract management processes include contract planning, procurement, administration, and dispute settlement These are given in **Table M.1**:

Table M.1

Construction Contracts Management Processes

Process	Tools, Techniques and Practices	Outcome
Contract Planning	Procurement Options Contract Types Contract Arrangements	Procurement Plan
Contract Procurement	Notice of Tender Pre-qualifying of potential contractors Preparing contract documents Invitation to Tender Contractors Bids Bid Scrutiny Letter-of-Intent to selected bidder	Procurement documents Selection of suppliers and contractors Award of Construction Contracts
Contract Administration	Obligation of the participants Production performance controls Scope change control Advance payment control Bonds and securities Penalty for non-conformance to specified completion time Termination provision Contract Closure	Contracts Scope Update Assets update Contract Audit
Disputes, Claims and Disputes Settlement	Anatomy of Disputes Claims preparation method ology Disputes Settlement Mechanism	Outstanding Disputes

This Appendix briefly covers the salient features of contract legal frame work, Forms of Contracts, Contract Administration, Time delays implications, Claims and Disputes Settlement Mechanism,

and obligations of contacting parties to harmonize contract management. Unless otherwise mentioned, all contract clauses referred in this Appendix are from FIDIC General Conditions of Contract 1992. Due to limited scope, the *interpretation of Contract Clauses* is not covered in this Appendix.

❑ M.2   CONTRACT LEGAL FRAMEWORK

A contract is an agreement between two parties which is enforceable by law. This agreement may be for selling, or buying any commodity, borrowing or spending money, leasing or hiring any property, construction of a facility or rendering any services and so on. The contracts concluded in India are governed by the Indian Contract Act 1872 and the Indian Arbitration & Conciliation Act 1996. Section 10 of Indian Contract Act 1872, defines that all agreements are contracts, if they are made by the free consent of parties competent to contract, for a lawful consideration and with a lawful objective. Contract Act lays down the terms and conditions for an agreement to become a contract. These conditions include:

1. **Lawful object**. The proposal and the object of the agreement must be lawful.
The object must not be illegal, immoral or opposed to public policy. Object must not be unlawful such as: A agrees to pay-sum of Rs. 5000/- to B if B rides the bicycle during night without light on his bicycle in a place where such an act is forbidden by law. A agrees to pay a sum of Rs. 1000/- to B if B destroys the garden maintained by A. It is immoral.

2. **Mutually agreed offer and its acceptance**. There must be a lawful offer from one party and the lawful acceptance by the other party.   An offer must be made with the intention of creating a legal relationship. Offer must involve accomplishment of a definite and possible act and must not be vague. A mere statement of intention or an enquiry is not an offer. Acceptance must be unconditional and absolute for all terms of the offer including time and mode of communication.

3. **Lawful consideration**. In a legal contract, it is necessary that there should exist a consideration (barring a few exceptions given in the law). Total absence of consideration will render it unenforceable. Consideration must be real and lawful.

In construction contracts, consideration is generally specified in the form of down payment from the promisor to the promisee, for executing the proposal. If one party fails to perform its obligation, the other party can resort to legal action to claim specified compensation due to the default of the first party.

4. Free Consent of Competent Contracting Parties. The parties entering into an agreement must be competent i.e. not disqualified either by infancy or insanity or by other special qualification by personal law or of unsound mind, when the contract is made. The agreement must be based on their free consent.

5. Contract Completion Time. Time can be essence of contract provided it is so expressed in words in the Contract Agreement and appears as such when read with other provisions of the

contract. For example, if the contract completion is fixed time, then time is said to be essence of contract.

❑ M.3   FORMS OF A CONSTRUCTION CONTRACT

Construction contract documents include general conditions based on standard forms of construction contract like those used in organisations like Public Works Department (PWD), Military Engineering Services (MES), Construction Industry Development Council (CIDC) and other construction related organisation. Contract form in each of these organisation varies. Generally, contract form can be divided into two parts: Part-1 General Conditions of Contract and Part-2 Special Conditions of Contract. General Conditions contain the standard form whereas Special conditions cover modifications in General Conditions in order to provide further or supplementary information,

International construction contracts generally follow FIDIC Form of Contract. FIDIC (Fédération Internationale des Ingénieurs-Conseils) was founded in 1913 in Belgium and the original founding countries were France, Belgium and Switzerland. The United Kingdom signed up in 1949 and the USA in 1958, some of the newly industrialised countries became members in 1970s, thus making it truly international.

FIDIC has developed various forms of contracts to suit requirements of different modes of tendering agency requirements. The various forms of contracts developed by FIDIC from its inception shown in **Table M.2**:

Year	FIDIC Form of Contract
1987 Red Book	Conditions of Contract for Works of Civil Engineering Construction *Red Book*, 1987, 4th ed. (Last Edition) Reprinted in 1992 (+ DRB Supplement 1996)
1987 Yellow Book	Conditions of Contract for Electrical and Mechanical Works, *Yellow Book*, 1987, 3rd ed. (Last Edition) (+ DAB Supplement 1997) (Revised version 1999)
1991 White Book	Client–Consultant Model Service Agreement, *White Book*, 2nd ed.
1995 Orange Book	Conditions of Contract for Design-Build and Turnkey, *Orange Book*, 1st ed.
1999	Four new standard forms of contract i.e. *Red Book, Yellow Book, Silver Book* and *Green Book*.
2007 Gold Book	Seminar edition of *Gold Book* for Design, Build and Operate Contracts.

The Red Book.   It is used when the contract is of the measurement or bill of quantity contracts. In these types of contracts there is separation of construction and design (Owen, 2003). This form of contracting goes back to the mid-nineteenth century and is widely used; however it is decreasing in popularity. This is because more and more lump sum contracts are being used where the risk is allocated to the contractor (Anderson, 2002).

The Yellow Book.   Conditions of contract for plant and design-build are recommended for the provision of electrical and/or mechanical plant, design and execution of building or engineering works. Under the usual arrangements for this type of contract the contractors design and provide in accordance with the employer's equipment, plant and/or other works, which may include any combination of civil, mechanical, electrical and/or construction works (FIDIC Conditions of contract for construction, 1999).

The General Conditions that follow are the Conditions of Contract for Construction for Building and Engineering Works Designed by the Employer, Multilateral Development Bank Harmonized Edition June 2010, prepared by the FIDIC available at FIDIC MDB June 2010 is exclusive for the use of ADB borrowers and their project implementing agencies as provided under the License Agreement dated June 9th, 2005, between the ADB and FIDIC.

The FIDIC General Conditions of Construction Contracts, edition 1987 updated 1992, which is generally used in multinational contracts, is referred while illustrating general conditions in this chapter.

❑ M.4   CONSTRUCTION CONTRACTS ADMINISTRATION PRACTICES

The term contract administration is used in a broader sense to cover contract related functions performed by the Employer/Client project manager, the engineer and the contractor's manager. They have a common goal of completing the project on time within specified costs and quality specification. However, their roles differ. The words 'Employer', 'Client' and 'Owner', used in the text are interchangeable.

M.4.1   Role and Obligation of the Participants

Construction at the site of the contracted project is supervised and carried out by two separate agencies. These are the Employer/Client team led by the project manager, and the contractor's workforce managed by his construction manager.

The key-persons in a project who deal in contract matters are the Employer/Client project manager assisted by his contract manager/quantity surveyor, contractor's manager and the Employer/Client appointed engineer

incharge. The term contract administration is used in a broader sense to cover contract related functions performed by the Employer/Client project manager, the engineer and the contractor's manager. They have a common goal of completing the project on time within specified costs and quality specification. However, their roles differ.

Role and obligations of the client project manager.   It is the Employer appointed client project manager who plays the dominant role; he represents the Employer/Client and acts as the boss at the site. It is he who is accountable to the Employer/Client for the construction of the project. He, on behalf of the Employer/Client, performs the following duties in discharging the main obligations under the FIDIC contract:

1. Appoint the Engineer (*Clause 1.1*)
2. Handing over of site without any construction or encumbrance in the manner as provided in the contract. (*Clause 42*)
3. Ensure soundness of the design and specification (as stipulated in the contract)
4. Provide drawings, instructions/decisions (as stipulated in the contract)
5. Make payments on time (*Clause 60*)
6. Ensure safety of employers' staff (*Clause 19.2*)
7. Bear cost of insured employer's risks. The contractor shall bear no liability for special risks (*Clauses 20 and 65*)

On contractual matters, the Employer/ Client Contract Manager/Quantity surveyor assists the Project Manager.

Role and Obligations of the Contractors.   Construction contractors form the backbone of the construction activity at pr oject site. It is the contractor who estimates the work, plans the execution, inducts resources, executes the work under pressure, incurs costs and takes the risk of cost overruns. Contractor bears the cost of input resources employed by him for the execution of the work. These input resources and site expenses include cost of his manpower, materials, machinery, and capital. He also incurs expenditure on interest on loans, statutory payments, insurance, depreciation and so on. In addition, like the Employer/Client, he has also to control his finances to meet the cash requirements from time to time. His motto is to maximise profits by effective cost control. In fact, he is the hub around which the construction industry revolves.

At site, the contractor's construction manager manages the work execution as well as the resources, and the workforce. He operates to achieve the contractor's objectives, which include optimising profit, maintaining a cooperative and harmonious relationship with the project manager and others engaged in the construction activity at site.

Despite the frequent crises during the execution of the contract and the risks at the time of procuremeppznt of work, the contractor's obligation is to complete the contracted work to his Employer/ Client satisfaction, on time, within budgeted cost, conforming to quality specifications, and at the same time avoiding conflicts and disputes, as business survival depends upon his performance. Contractor main obligations under the contract include:

1. Design (as provided in the contract), execute and complete the works and remedy any defects with the provisions of the contract. He shall give prompt notice to the engineer with copy to the Employer for any error, omissions, fault or other defects in the design or specifications of the works (*Clause 8.1*).
2. Take full responsibility for the adequacy, stability and safety of all site operations and methods of construction (*Clause 8.2*).
3. Furnish bank guarantee for mobilisation advance when applicable along with the performance guarantee within 28 days after receipt of the acceptance letter (*Clause 10.1*).
4. Prepare and submit the program for execution and cash flow estimate to the engineer for his consent within the time stated in the contract (*Clauses 14.1, 14.2 & 14.3*).

5. Provide evidence to the employer that all the insurances required under the contract have been effected and notified to the Engineer (*Clauses 21, 22, 23, 24, 25*).
6. Comply with the national, state and local statutes, regulations and laws (*Clause 26.1*).
7. Commence the work after receipt of the notice to commence (*Clause ??*).
8. Conduct test(s) of the respective kind and in accordance with the Engineer's instruction, of all materials and workmanship, where required during execution of work (*Clause 36*).
9. Remedy any defect or fault for which the contractor is liable during defect liability period. (*Clause 49*).
10. Submit a detailed statement within the specified period after the takeover certificate in respect of the whole work containing all information as contained in *Clause 60.5*.
11. Submit to the Engineer for scrutiny a draft final statement with supporting documents which should show the information required within specified time after issue of defect liability certificate (*Clause 60.6*).

Role of the Engineer-in-Charge.   It is the Employer/Client appointed engineer who endeavors to achieve fit-for-use contracted work on time, within the cost and quality specifications. He assists the project manager and the contract manager to perform their contractual duties. In most of the contracts, all instructions and the correspondence of the Employer/ Client is sent to the contractor under the signature of the engineer. In fact at site, the engineer is the controller of the contract.

Engineer as defined in FIDIC Part-I 1992 is the person appointed by the employer to act as engineer for the purpose of the contract and is named as such in the Part II of the Contract Conditions. Duties and powers of the 'engineer' are specified in the Part-1 General Conditions of the Contract. It may be supplemented in Part-2. He has many roles to play. He acts as an agent of the employer (*Clause 2.1*) and as an independent person in quasi-judicial capacity (*Clause 2. 6* and *Clause 67*). He is also required to have due consultation with employer and contractor before deciding certain matters as per the provision in the contract. He certifies all the contractor's advance and final payment certificates prior to payment (*Clause 2.1*). Any such decisions, opinion, consent, expression of satisfaction, or approval, determination of value or action may be opened up, reviewed or revised as provided in *Clause 67*. The engineer's duties are specified in Part-1 General Conditions of the Contract are contained in the various clauses.

M.4.2   Production Performance Control

As an agent of the Employer/Client, the Engineer ensures compliance by the contractor to the contract's terms and conditions, and to make sure that the end product is produced as per the requirement of the Employer/Client and is fit-for-desired purpose.

M.4.3   Approval of Execution Programme

In FIDIC Part 1, preparation and submission of programme of work and cash flow is the responsibility of the Contractor (*Clause 14*). The Contractor, within the time stated in Part II of the Conditions

after the date of the Letter of Acceptance, is required to submit to the Engineer for his consent a programme, in such form and detail as the Engineer shall reasonably prescribe, for the execution of the Works. The Contractor shall, whenever required by the Engineer, also provide in writing for his information a general description of the arrangements and methods which the Contractor proposes to adopt for the execution of works.

In FIDIC Part-II, the period for the submission of programme is specified. For example, the contractor can be instructed to submit a programme for the execution of the work to the Engineer for his consent within 14 days from the date of receipt of the Letter of Acceptance. This programme shall include:

1. A bar chart and the connected network time analysis chart supported with Primavera or MS Project software showing all major activities from commencement of work to completion to be performed each month together with the mechanical equipment, materials and labour which shall be deployed on such activities justifying his capability of achieving the completion of work within the stipulated period of completion. The programme shall not be unbalanced and shall be based on the achievement outputs calculated and demonstrated in the method statement. An 'S' curve illustrating anticipated cumulative turnover and the anticipated cumulative progress shall be superimposed upon the bar chart.

2. A separate time based monthly forecast indicating the Contractor's proposals for the mobilisation of men, materials and equipment covering the duration of the contract.

3. A quality assurance plan covering all aspects of the work shall be adopted for this work to ensure the desired quality. Detail of the procedures shall be submitted to the Engineer for his consent at least three month prior to execution of respective activity.

4. The detailed cash flow estimate shall be submitted within 28 days of the approval of the work programme by the Engineer or two months from the date of commencement of the contract, whichever is earlier.

If the work programme submitted by the contractor is deemed in any way incomplete or unacceptable by the Engineer, the Contractor shall be given 15 days to revise and re-submit it to the Engineer's satisfaction. Until full compliance is achieved, the Contractor's obligation "to commence the Works at site" (*Clause 41.1*) shall be deemed unfulfilled.

M.4.4   Other Important Conditions of Contract

Contractor's Extension of Time and Cost/Cost Alone Entitlement.   Time is the essence of a contract. In case of time delays due to reasons beyond contractor's control, the contractor is entitled to extension of completion time and also cost as stipulated in the following conditions of the FIDIC contract:

Extension of time for completion due to causes outside the control of contractor and for extra work within deviation limit is admissible. Where the extension of time is granted due to reasons

Clause	Brief Description of Event	Extension of Time	Cost
6.4	Delay in supply of drawings or instructions.	Yes	Yes
12.2	Encountering unforeseen physical obstructions/conditions.	Yes	Yes
27.1	Where contractor suffers, delays and cost due to Engineer instruction relating to discovery of fossil article of value.	Yes	Yes
36.5	Where it is found on carrying out test not provided in the contract that material/plant/workmanship is found in accordance with contract.	Yes	Yes
40.2	Suspension of Work	Yes	Yes
42.2	Failure to give possession of site	Yes	Yes
44.1, 2 & 3	Extension of Time	Yes	Yes
51 & 52	Variations	Yes, as per clause 44	Yes
69.4	Contractor's entitlement to suspend work where the Employer fails to pay to the Contractor his due amount.	Yes	Yes
17	Incorrect setting out data given to Contractor.	—	Yes
20.3	Damage of work covered under Employer's risk.	—	Yes
38.2	When on uncovering on Engineer's instruction no fault found.	—	Yes
50.1	When on search by the Contractor for any defect/shrinkage or any fault on Engineer Instructions no fault of Contractor found.	—	Yes
58	Provisional sums	—	Yes
65.3	Rectification of damage caused to work/plant/material by special risk.	—	Yes
70.2	Increase in cost due to subsequent legislation including regulation.	—	Yes

attributable to Employer, such as late handing over of site, late issue of drawings/instruction/approval, suspension of work within the specified period, special risks, if delay is for limited period and delay due to adverse physical condition and artificial obstruction, contractor is entitled not only for extension of time but for extra cost and both should be determined by the Engineer without delay and simultaneously to avoid cash flow problems to contractor.

Contract Documents Discrepancy.   The contract is to be construed as a whole. Interpretation which brings harmony between different parts of the contract documents is to be preferred. In order to resolve discrepancies, the contract documents specify the priority in which the documents are to be considered. The priorities laid down in FIDIC Part-1 (*Clause 5.2*) are as follows:

The several documents forming the Contract are to be taken as mutually explanatory of one another, but in case of ambiguities or discrepancies the same shall be explained and adjusted by the Engineer who shall thereupon issue to the Contractor instructions thereon and in such event, unless otherwise provided in the Contract The priority of the documents forming the Contract shall be as follows:
The Contract Agreement (if completed);
The Letter of Acceptance;
The Tender;
Part 11 of these Conditions;
Part 1 of these Conditions; and
Any other document forming part of the Contract.

M.4.5   Scope Change Control

During the execution stage, the changes involving additions and alteration is in the scope of the contract are inevitable. These changes include:

1. Administrative changes that do not affect the substantive rights of the parties.
2. Changes and modifications are ordered in writing, directing the contractor for action in the terms of the contract.
3. Supplemental agreement requiring changes that are accomplished by mutual action of both the parties.
4. Constructive changes that cause a contractor to perform work differently than required by the written contract.
5. Effective change instructions such as acceleration of performance and ensuring cooperation in progressing works as per the contract.

The scope change clause in a contract authorises the owner to order changes in the scope of work.

A contractor is obliged to follow such change instructions, but he is to be reasonably compensated by the Employer/Client with time extension and cost as applicable.

M.4.6   Sub-Contractor Approval

The engineer's consent in writing is required by the contractor for engaging/employing a sub-contractor for a work. Since the prime contractor remains fully responsible for the work, the engineer normally approves the sub-contractor unless he finds him unsuitable for the job. Similarly for the removal of a sub-contractor due to unsatisfactory performance, the discretion rests with the prime contractor but the approval of the Engineer/Employer is necessary.

M.4.7   Interim Valuation and Payment Control

The conditions of the contract provide for advance payment to be made to a contractor on monthly basis for the completed and in-progress work, permanent materials brought at site and other

advances, as per the contract. Each contractor's interim statement shall also include amount claimed in respect of days work and extra approved work. The interim payment bill is submitted by the contractor through the project engineer for certification and onward transmission to appropriate authorities.

The FIDIC contract (*Clause 60*) provides a mechanism for payment to the contractor. Certification by the engineer is necessary before the contractor becomes entitled to the payment from the employer. The employer is contractually bound to make payment within 28 days of the delivery of the interim certificate and within 8 weeks in respect of final certificate or as specified in the contract. The employer is also liable to pay interest in case of delay. Further, if the employer fails to pay the contractor dues under the certificates mentioned above within 28 days after expiry of the time stated above, it would amount to default of the employer entitling the contractor to terminate the contract by giving a due notice.

The responsibility for preparation of final account lies with the contractor. The final accounts should contain items of all payments for which the contractor considers that he is entitled. All payments shall be supported with documents.

M.4.8   Contract Termination Control

A contract can come to an end by any of the methods mentioned below:

- By mutual agreement between the contracting parties;
- By completing the task and as stipulated in the contract;
- By breach of contract by one party;
- By unforeseen circumstances like bankruptcy and impossibility of task execution;
- By making a new contract to substitute the old; and
- By termination of the contract by either party.

The termination of a contract due to contractor's fault is the most serious matter. Based on the type of contract, terms and conditions, the Employer/Client has the right to terminate a contract due to contractor's fault. Some of the reasons for termination of contract after repeated notices by Employer/Client to the contractor could be due to:

- Failure to observe statutory laws and rules;
- Failure to induct resources to maintain/accelerate adequate rate of progress;
- Failure to conform with the contract specifications;
- Failure to obey instructions for properly co-ordinating activities with other contractors to avoid work interference;
- Failure to pay the sub-contractors or suppliers for resources supplied to the project;
- Filing for bankruptcy or committing other similar acts; and
- Sub-letting the work without the approval of the contract administrator.

If a contract is terminated due to fault of the contractor, then the contractor may not be entitled to the compensation but the Employer/Client may claim cost of completion for the balance work.

The Employer/Client can also terminate the contract, if he wants to discontinue the project for his convenience say due to change of need for the project or the budgetary constraints. However, in such cases, the Employer/Client will have to suitably compensate the contractor.

The contractor also has a right to terminate the contract in certain cases such as if the work is stopped by a court order and the Employer/Client fails to issue certified payments. Under *Clause 69.1* of FIDIC, if the employer has failed to pay the amount due under the certificate of Engineer within 28 days or the time specified in the agreement or if the Employer/Client is interfering with obstructing/refusing such certificate of payment, the contractor can terminate his employment under the contractor by giving 14 days notice.

It should be noted that termination of contract is a serious matter and must be considered as a last resort after taking due legal advice.

M.4.9 Formal Correspondence Guidelines

All correspondence initiated by the contracting parties is for documentation purposes and it may have to be referred to at a later date. Therefore, each communication must be clear, concise and comprehensive. Each document should identify an issue, record the history and lead to an action. An effective formal correspondence, as far as practical, should conform to the following rules:

- Deal each contract separately;
- Take up one issue or a small group of issues in one letter;
- Start with background or reference or both, in brief;
- Preferably use a single page for each letter;
- Avoid unnecessary/superfluous writing;
- Use simple language and be factual;
- Adopt cause-and-effect style; and
- The last paragraph of the letter should bring out as to what you want the addressee to do.

M.4.10 Close-Out

For proper closing of a project:

a. The post-completion maintenance is usually entrusted to an agency familiar with the construction. In most cases, the contractor responsible for construction is given this responsibility for one year after completion and this aspect is included in the scope of work of the contractor.
b. A proper record of the operating instructions and as-built drawings is maintained.
c. The staff and workers necessary for operating and maintaining the facility are trained prior to its taking over.
d. The site is cleared of the left-outs of the construction and unwanted materials.
e. The Employer/Client fully safeguard his interests prior to rendering the completion certificate to the contractor, and also before making the final payments.

After completion by the contractor, it is the project team of the Employer/Client that hands over the project to him. The team also prepares a project completion report which includes the scope and schedule of work, the important events, the contract executed, the addresses of the suppliers of materials and equipment, the equipment maintenance manual, the as-built drawings, the costs involved, the problems encountered during execution, the lessons learned and the minor defects noticed at the time of handing over.

❏ M.5   DISPUTES, CLAIMS AND THE MODE OF SETTELEMENT

M.5.1   Claim Management Processes in Outline

A claim is a deemed or request for something considered due or believed to be due to a contracting party (claimant) for compensation on account of unsettled dispute with the other party. The term 'claim' differs from a settled change order. A change order, accepted by a contracting party with implications and without any reservations, is not a dispute and hence it cannot be cause for a claim. A claim cannot be adjusted unless it becomes a dispute.

The claim management of the client as well as contractor focuses at prevention of disputes, categorising of claims for unresolved disputes, preparation of claim documents and lastly processing of claims using claims settlement mechanism as specified in the contract agreement till the claim is resolved. These aspects are described in subsequent paragraphs.

M.5.2   Disputes Anatomy and Prevention

In the context of contracts, a dispute arises, when the contracting parties differ on a monetary claim projected by one party against the other on a specific issue in a given situation, at a particular time under the contract agreement. It reflects the differences in the opinion of the contracting parties. In simple words, a dispute represents a situation where the contracting parties agree to disagree on a particular claim, subject to the proviso that the dispute is to be settled within the framework of the contract agreement. In all contracts, a provision is made to deal with such claims arising out of the dispute.

There is a famous saying, "where there are contracts, there will be disputes." In construction contacts, the disputes are inevitable. Even with the best of intentions of all concerned parties, no construction document can possibly cover all the complexities of a construction process as no two construction project are alike. Disputes are unavoidable. Resolution of disputes is therefore an important subject.

In general, dispute in a construction contract can arise due to a number of reasons such as:

- Discrepancies in site data, drawings and quantities;
- Delays in handing over of site and releasing of drawings;
- Disagreement on specifications and extra works;
- Inaccuracies in the contract documents;

- Differences in the interpretation of contract terms and conditions;
- Delay in the timely supply of Employer/Client responsibility, materials and payments by the owner;
- Unforeseen adverse situations like strikes, changes in working conditions, accidents, political unrest etc.; and
- Implications of delays due to natural forces such as those resulting from floods, earthquakes, severe weather and acts of God.

A contract makes provision for raising claims for compensation by both the parties that is the Employer/ Client and the contractor. The dispute clause provides the specific procedure for resolution of serious problems. It may detail a progressive series of steps (such as appealing to higher authorities) or may simply take the ultimate option (arbitration). In India, "The Arbitration and Conciliation Act, 1996", which is generally in conformity with UNCITRAL (United Nations Commission on International Trade Law) for international disputes provides the mechanism for settlement of the contractual disputes. Dispute and performance are interrelated. If the disputes are not resolved in time, the construction process gets prolonged with adverse effect on completion time, construction costs and specified quality.

The aim of contracting parties should be to avoid, minimise and resolve disputes expeditiously in a fair manner as and when they occur. The disputes can be avoided by equitably and fairly framing of the contract documents. These can be minimised by properly administering the contract during execution phase and these can be resolved through dispute resolution mechanism.

The succeeding paragraphs focus on claims by contractor and the similar approach is applicable in case of the Employer/Clients claim on the contractor.

M.5.3 Claims Categories

The claims can be divided into three categories, that is, Contractual Claims, Extra-Contractual Claims and Ex-gratia Claims.

Contractual Claims.   These are due to happening of certain events or circumstances for which contract provides express remedy. Settlement of these claims is within the powers of the project manager.

Examples: Suspension of work, delay caused due to artificial obstruction, late possession of entire site, and delay in release of interim payments beyond the period specified in the contract.

Extra-Contractual Claims.   These arise where contract does not provide express provision and therefore these are to be based on principle of common law. Project manager does not have the authority to decide these claims and he can make his recommendations to the Employer/Client.

Examples: Claims relating to prolongation/disruption/dislocation due to default of the Employer/Client engineer, unreasonable orders, unreasonable delay in inspecting work and testing of materials, and delay caused by nominated sub-contractors.

Ex-gratia Claims.   These arise where no ground exists either in the contract or in common law. These claims are nothing but seeking sympathy for financial compensation from the Employer/Client on account of loss which happens either due to absurd rate or due to circumstances beyond the control of the contractor but outside the responsibility of the employer. The Employer/ Client can consider ex-gratia payment for such claims depending upon the nature of the case.

M.5.4   Processing Claims

Registering Claims.   Claim is registered by giving a notice. Contract provisions enable a contractor to give notice of his intention to claim additional payment whenever the cause for such an action arises. Failure on his part to comply with this requirement may prejudice credibility of such claims.

Establishing Claims.   The claims are established from the correspondence in which the fact of matter and reasons for lodging or rejecting the claim by the Employer/ Client are given. A claim is also supported from the record of losses suffered especially when these are in the full knowledge of the Employer/ Client.

Claim Presentation.   Formation and presentation of the claim is an important aspect of dispute resolution. A typical structure for presentation of a claim should be:

- Background;
- Who are the participants;
- Project phase where claim arose;
- Contract terms;
- Intentions of claimant (expectations while quoting);
- Actual experience;
- Conclusion (with suffering);
- Damage; and
- Arguments based on records/documents.

Every claim has to be established based on documentation. Contractor has to foresee the possibilities of claims and keep the supporting records. As claim situation can occur at any time, these documents must always be kept up-to-date.

   From the owner's side claim prevention as a management technique needs careful preparation of contract, adopting methodology to resolve construction difficulties, and willingness to share risks equitably. The owner's manager must keep his own records to verify, counter or recommend the claim for grant of equitable treatment to the contract.

M.5.5   Modes of Resolving Disputes

Dispute can be resolved by conciliation, arbitration and litigation. In the recent past, conciliation is emerging as the speedy mode for settlement of disputes as compared with arbitration and litigation.

Conciliation implies settlement of dispute through mediation by third party. It can be negotiated settlement, conciliation by a mediator, or conciliation by setting up Dispute Review Board (DRB)

Conciliation through negotiations.　In this case, both the parties willingly discuss the dispute and arrive at a settlement without the intervention of any third party. It is a non-binding procedure.

During negotiations unequal bargaining power plays an important part in hastening a settlement. Capitulation can also occur when one party gives in to the other, either because it has realised the strength or reasonability of the other's stand or because it feels that the advantages to be gained by capitulation outweighs those of pressing its claims, even though they must be quite.

Conciliation through mediation.　It is a non-binding procedure in which an impartial third party, the conciliator/mediator, assists the parties in reaching a mutually satisfactory and agreed settlement of the dispute.

Figure M.2

Processing of Claim Settlement
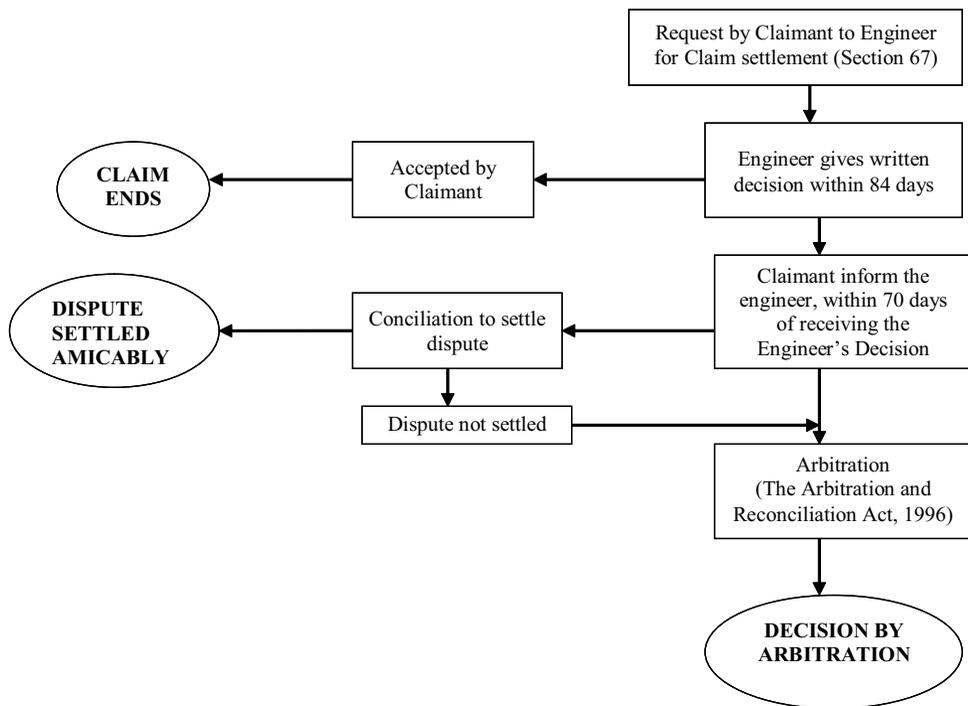
Conciliation by setting up Dispute Review Board (DRB).　DRB comprises of persons experienced with the type of construction involved in the works and interpretation of documents. An independent body as agreed by both the parties appoints it. Disputes can be referred by either party to

the DRB. Board recommendation(s) are not binding. Any dispute for which the recommendation(s) is/are not accepted may be referred in writing by either party to arbitration by written notice to the other with copy to the Engineer and the Board. By this method, most of the disputes except those of critical nature get resolved during the execution of work itself.

The Employer in Part-II may appoint an alternate Dispute Resolution Board to act as mediator. To quote example, in the Part-II of a contract Dispute Resolution Board role was stipulated as under:

"If any dispute arises between the Employer and the Contractor in connection with or arising out of the Contract or execution of the Works whether during the execution of the Works or after their completion; whether before or after the repudiation or other termination of Contract, including any disagreement by either party with any action, inaction, opinion, instruction, determination, certificate or valuation of the Engineer, the matter in dispute shall in the first place be referred to the Dispute Review Board (the Board)."

Advantage of Conciliation

- It is fast and uncomplicated;
- It minimises damage to the business relationship of the parties and the project itself;
- It minimises the expenses of resolving the dispute; and
- It is private and avoids bad publicity.

Disadvantage of Conciliation

- It can be stopped by any party at any time; and
- It does not establish any legal precedent for arbitration.

Arbitration.   If conciliation/mediation fails, then the next stage is arbitration. In this case, concerned parties approach a third party to arbitrate for settlement of their disputes. Usually all contracts contain an arbitration clause, but even in the absence of one, the parties are free to refer their disputes to arbitration by mutual agreement. Arbitration presupposes that the parties agree that there are some disputes, which they are not able to settle among themselves and that they feel that a third party, in whom both have confidence, will be able to decide the disputes to their satisfaction. Arbitration agreement also specifies the mode of appointment of arbitrator(s), and also includes such other provisions, which the parties may deem fit to incorporate. The decision given by the arbitrator is called an Arbitration Award. Arbitration of disputes in engineering contracts comes under the category of commercial arbitration. Neither party can unilaterally revoke the arbitration agreement. The appointment of arbitrator, conduct of arbitration, and publication and implementation of awards is as prescribed in the Indian Arbitration Act 1996.

In FIDIC, if Employer or Contractor is dissatisfied with the Engineer's decision, or if Engineer fails to decide in time, then Employer or Contractor may, before the 71st day after the 84 days period expired, give notice of his intent to commence arbitration, otherwise the Engineer's decision is final.

In FIDIC, arbitration may be commenced on or after the 56th day after notice to commence arbitration is given, whether or not any attempt at amicable settlement has been made.

Arbitration may be commenced prior to or after completion of the Works, and the obligations of Employer, Engineer and Contractor shall not be altered by reason of the arbitration being conducted during progress of the works.

Enforcement and challenge to the arbitration awards in India are governed by the Arbitration & Conciliation Act of 1996. Different types of awards dealt with in the 1996 Act are:

(i) Sections 34–36: Enforcement of 'Domestic Award'
(ii) Sections 44–49: Enforcement of 'Foreign Arbitral Awards' governed by the New York Convention.
(iii) Sections 53–59: Enforcement and recognition of 'Foreign Arbitral Awards' governed by the Geneva Convention.

Figure M.3

Conciliation and Arbitration Flowchart
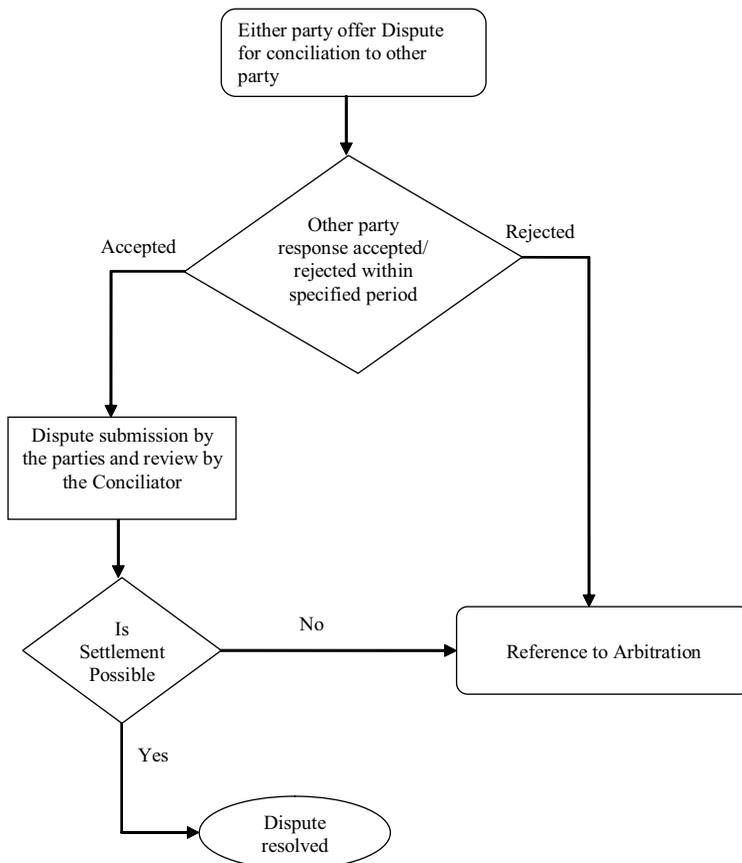
Litigation.   If the parties do not agree to refer the disputes to arbitration, then the aggrieved party can take up the dispute to the court. However, if an arbitration clause exists in the contract, the dispute cannot be contested in the court as the existence of arbitration clause acts as a barrier to litigation.

Advantage of Arbitration over Litigation for Settling Disputes.   The main advantages of arbitration over litigation are:

- Speedy decision, less expensive;
- In arbitration, both parties maintain goodwill, litigation can result in animosity;
- Arbitration proceedings are private and secret, court proceeding is a public affair;
- Arbitration proceedings can be convened at a convenient place, but in litigation the proceedings are generally held in the court; and
- Arbitration awards are generally final, whereas a court judgement can be contested in higher courts.

❑ M.6   GUIDELINES FOR MINIMISING PROBLEMS DURING CONTRACT ADMINISTRATION

Contract administration is not trouble-free. Both the owner and contractor face problems in administering contracts, but there are ways to minimise it. The problems in contract administration can be minimised, if the participants follow their professional practices, and administer the contract in a proper manner with mutual confidence. The following measures for improvement in contract administration both from employer's and contractor's side can go a long way in smooth execution of construction projects eliminating time and cost overrun cases, and disputes and arbitration to a considerable extent:

a. Awareness of legal implications of contractual matters.
b. Safety and welfare of workers must come first always and every time.
c. No compromise on quality of work.
d. Ensure site receives drawings and prompt decisions on technical matters.
e. Jointly plan and review costs, schedule, and technical performance.
f. Design and implement efficient contract change control system to enable prompt settlement of variations and claims.
g. Maintain documentation of contractual correspondence and proper recording of the site data.
h. Ensure contractor receives prompt payment of progress bills.
i. Ensure timely procurement and control of materials.
j. Use serviceable Construction Equipment.
k. Appreciate problems of all the participants involved in the implementation of the contract.

The most important factor that can contribute in smooth administration of the contracts is the proper selection of the Employer/Client and contractor project leaders. According the Employer/Client should select project team fully committed to work, having adequate experience, good exposure on project problems and courage to give prompt and fair decision. Similarly contractor should have a competent site manager and other members of his team, who can plan the deployment of required resources, execute work as per planning with quality better than specified, control performance, and lead his team to implement the contract work efficiently and effectively to the satisfaction of the stakeholders.

In the modern context, a contract is considered successfully accomplished, if the contract is completed:

- Within the allocated time period;
- Within the budgeted cost;
- At the proper performance or specification level;
- With acceptance by the customer/user;
- When the contractor can use the customer's name as a reference;
- With minimum or mutually agreed upon scope changes; and
- Without disturbing the main flow of the stakeholders.

A contract thus can be graded as having been completed successfully, if it is accomplished within time, cost and quality performance, all to the satisfaction of the Employer/Client, and where the contractor can quote the Employer/Client as reference for his role-model in the project.

Controlling Resources Productivity

The term 'productivity' as commonly understood, implies the ratio of output to input. But productivity conveys different meanings to different people. Some regard productivity and production capability as synonymous terms. Many link productivity to mean workers' output capability; they express productivity as work quantity produced per man-hours of input. In USA Department of Commerce, Productivity is defined as dollars of output per man-hour of input. Some consider productivity as performance output in dollars for every dollar of input.

In construction context, resources productivity is the physical output per unit of planned effort. More work done with the same input implies higher productivity, and less work done shows lower productivity than the planned productivity. Standard output or planned productivity is the predetermined planned output under normal working conditions, where as, actual output or actual productivity is what is achieved during implementation. Productivity measures the trends in the performance of these resources. Productivity index indicates the productivity trend.

$$\text{Resource productivity variance} = \text{Standard productivity} - \text{Actual productivity.}$$

$$\text{Resource productivity index} = \frac{\text{Acual productivity}}{\text{Standard productivity}}.$$

Physical resource inputs at the construction project site include man, materials and machinery. These inputs produce outputs in the form of work. The success of a project depends upon the performance of these input resources. Performance implies the degree of achievement. Productivity provides the scale to measure the performance of these input resources. The various productivity parameters, which need to be controlled in construction projects, are labour productivity, equipment productivity, and material productivity. In this chapter, various terms connected with the resource productivity imply the following:

(1) Workers' productivity. It defines the Quantity of work done per man-hour or crew hour

$$\text{Workers' job productivity} = \frac{\text{Work done units}}{\text{Effort in manhours or crew hours}}$$

$$\text{Workers' job productivity variance} = \text{Standard productivity} - \text{Actual productivity}$$

$$\text{Workers' job productivity} = \frac{\text{Work done units}}{\text{Effort in manhours or crew hours}}$$

(2) Equipment productivity. It stands for quantity of work done per equipment hourw

$$\text{Equipment job productivity} = \frac{\text{Work done units}}{\text{Effort in equipment hours}}$$

$$\text{Equipment productivity variance} = \text{Standard productivity} - \text{Actual productivity}$$

$$\text{Equipment productivity Index} = \frac{\text{Equipment actual performance}}{\text{Equipment standard performance}}$$

(3) Material productivity. It donates quantity of work done per unit material. Material wastage variance for a given work is the difference between standard material wastage and the actual material wastage.

Material Standard quantity = Quantity of work planned per unit of material
Material quantity variance for given work = Standard quantity planned
Actual quantity consumed

$$\text{Material productivity Index} = \frac{\text{Material actual consumption}}{\text{Material standard quantity}}$$

Productivity control aims at ensuring the efficient utilisation of the input resources of man, materials, and equipment, and forecasting changes in productivity of these direct resources. The efficient utilisation of resources is accomplished by identifying causes of wastage at the project site with a view to minimise wastage. The causes of wastage are located by analysing variances between standard and on-site actual productivity.

The methodology used for controlling each of the productivity parameters is similar. It can be divided into four stages, i.e. defining the control purpose, measuring the actual performance, computing productivity performance variance and, identifying causes for these variance and applying corrective measures as necessary. Though it is difficult to replace skilled workers by machines, the corrective remedial actions include but are not limited to the following:

- Replacing unskilled labour by machines, wherever feasible, in jobs like loading, unloading, shifting, bar-cutting, etc.;
- Using appropriate and efficient tools as equipment;
- Constantly improving the methods of production;
- Increasing productivity through improved working conditions and incentives;

- Implementing the job-oriented financial incentive schemes; and
- Training workers to overcome the initial learning period.

This chapter is divided into the following sections:

1. Labour Productivity Control
2. Equipment Productivity Control
3. Materials Productivity Control
4. Guidelines to Safeguard Workers Safety, Health and Protection of Environment
5. Role and Functions of Construction Managers in Improving Resources Productivity

❑ 14.1   LABOUR PRODUCTIVITY CONTROL

Labour productivity achieved at the site for a given work provides a measure of the labourer's efficiency. It shows the total time for which the labourer was employed at work, the time he was productive on work and the time he remained unproductive. Studies carried out at construction sites reveal that the labourer's productive work time varies from 50%–70% of his total employment time, and the remaining time is wasted for various reasons such as idle waiting, unnecessary travelling, late starting, early quitting, unscheduled breaks, and delays in the receipt of tools, materials and work instructions. Labour productivity can be improved by cutting down such unproductive time of the labourers. The control process involves accounting of actual productivity, comparing the actual with the standard, analysing the causes for variations between actual and standard, and finally taking remedial measures to improve productivity.

14.1.1   Labour Productivity Accounting Methodology

The project labour accounting system is designed to serve many purposes. It enables the computation of accurate payment to the labourers. It provides data for the evaluation of labour productivity for various tasks and it facilitates the estimation of labour costs of works executed.

Labour accounting system provides information and record-keeping needs of all the project departments, especially those of personnel, accounting, costing and planning. A typical labour accounting system can be modelled as shown in **Figure 14.1**.

The input necessary for labour productivity accounting are the time-keeper's daily time records for the labourer, the foreman/supervisor's daily labour employment record and the quantity of work produce in a given time.

This data is processed by the labour productivity centre to determine the actual labour productivity, the labour forecast and the labour costs.

14.1.2   Time-keeper's Time Record

The first step in productivity evaluation is to record payable time. The labour's time account is maintained by the time-keeper and the basic document used for this purpose is the time-card. A time-card records the daily attendance of the worker. It contains details of his trade category and

Figure 14.1

Typical Labour Accounting System

```
 ┌──────────────┐       ┌──────────┐       ┌──────────────────┐
 │ Administration│◄──────│ Time card│──────►│ Deployment centre│
 │    centre     │       └──────────┘       └──────────────────┘
 └──────────────┘                                     │
         │                                            │
         ▼                                            ▼
 ┌──────────────┐                           ┌──────────────────┐
 │   Pay-roll   │                           │ Productivity Centre│
 └──────────────┘                           └──────────────────┘
         │            ┌──────────────┐               │
         │──────────► │ Productivity │◄──────────────│
         │            │   analysis   │               │
         │            └──────────────┘               │
         ▼                    │                       ▼
 ┌────────────────┐           ▼             ┌──────────────────┐
 │Labour cost     │◄────────────────────────│ Labour forecasts │
 │forecasts       │                         └──────────────────┘
 └────────────────┘
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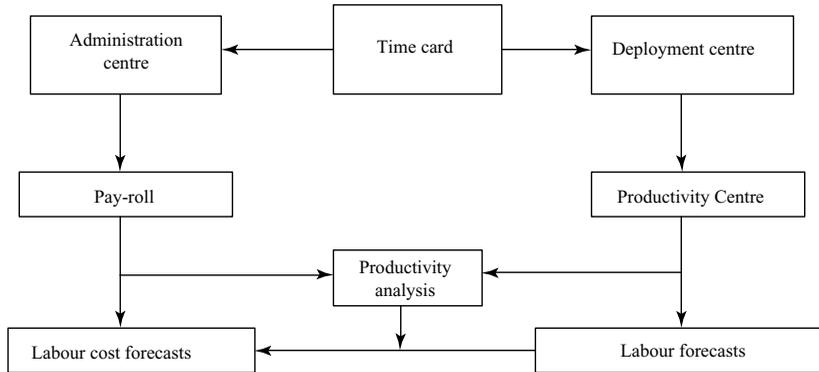
possibly, the task in which he is employed. The design of the time-card depends upon the requirements of the information system. A specimen is shown in **Table 14.1**.

Workers' time-card showing daily attendance data in the form of time-in and time-out, duly completed, is submitted by the time-keeper to the personnel department at specified intervals for making payrolls. It is important to remember that the labour force's attendance time record affects every worker at the project site as it forms the basis of wage calculation.

Time-card data ensures that a worker is paid exactly what is due to him. Accounting for time and wages has to be accurate and timely so as to avoid human relation problems, and any temptation for overpayment or fraud.

The daily labour card and weekly labour employment reports are sent to accounting, pay-roll, estimating and planning department. Their analysis is important part of Labour Accounting System. Some of these departments will require data by BOQ work items and others will prefer activity ID based. The allocation of work hours by activity ID or BOQ item both need consideration.Depending upon the nature of project work, the requirements of various departments can be suitably designed. Generally, nature of job (Activity ID) can be supplemented with the relevant BOQ Codes.

14.1.3   Foreman's Daily Labour Employment Report

The time-card data is then transmitted by the time-keeper in the form of the daily work attendance statement (specimen **Table 14.2**) to the concerned supervisor or foreman for incorporating the daily work progress and the employment time distribution. The foreman's daily labour employment data, at the end of the day, is forwarded by the foreman through his construction manager/project engineer to the monitor. This statement reveals the time and, activity-wise data, for which a labourer (or crew members) was employed on construction work or productive work, and it highlights the labour idle time breakdown with causes. In this statement the work done quantity can be inserted

Table 14.1

Typical Labour Time Card (Card Text and Size as per Time Recording Machine Specifications)

Attendance Time-Card   Week Ending...

No.		Category		Name		
Work Centre/Dept./Work Package						Cost Code
Normal Working Time						**Overtime**
Date	**IN**	**OUT**	**IN**	**OUT**	**Hours**	**Hours**
TOTAL						
For use by Accountant						
Normal wages		Overtime wages				Total
Deductions						
Amount payable						

on a daily basis or as and when the work-item or activity is completed. This employment statement can be maintained on a ledger or work sheet and it can be transmitted online to all concerned.

14.1.4 Construction/Site Engineer's Weekly Labour Productivity Report

The data reflected in the foreman's daily labour employment statement is used to determine the unproductive time and identify its controllable causes for the remedial action. This data, after scrutiny, is transferred by the project engineer or planning engineer into the weekly labour productivity report, a typical format of which is shown in **Table 14.3**. The reporting engineer can compile the weekly labour productivity report for each item of work separately, or combine them suitably in one report. The labour productivity report is of great value as it can be used to monitor labour performance and evaluate labour cost for each item of work. It provides a device to compare the operating efficiencies of different teams working at the project site for creating a competitive spirit. It helps to forecast the labour work force required for remaining similar works, and it can form the basis for developing labour productivity norms for use in future similar works.

14.1.5 Analysing Labour Productivity Performance

Labour productivity variances are determined by comparing the actual with the standard.

Labour productivity variance = Labour productivity standard – Labour actual productivity

Table 14.2

Foreman's Labour Employment Statement Daily Man-hour Report

Date	Act. ID/ BOQ-Code	Productive Man-hour						Non-productive Man-hour					Total MH
		Skilld Workers	Un-skilld Workers	Total (Nos)	Work Done Qty A	Work Done Qty B	Work Done Qty C	Absentees	Rework	Equip-ment	Materials	Other Reasons	
											Waiting for		

Table 14.3

Weekly Activity Productivity Report

Date	Crew mix			Actual MH on date	Actual MH cu-mulative	Quantity work		Produc-tivity actual	Produc-tivity standard
	Skill	Unskilled				Completed	Cumulative		

In order to consolidate the actual data, the value of labour productivity achieved is suitably plotted graphically on mean (X) and range (R) chart, where X represents the expected standard value and range indicates the variation trend from the standards.

To quote an example, **Exhibit 14.1** shows the actual productivity data in respect of steel fixing of the raft of each foundation module of a project, involving the construction of several similar size foundations. The standard productivity of steel fixing including cutting and bending was estimated as 90 kg/man-day, having eight working hours per day. The actual reinforcement fixing productivity data, plotted in the sequence of the completion of building foundation modules, shows the trend of productivity variation. Particularly in the initial four weeks, the actual productivity ranged from 60 kg/man-day to 75 kg/man-day which is lower than the standard productivity of 90 kg/man-day of eight hour and it gradually improved with the learning process till it records a near steady state level of 90–110 kg/man-day after 5 weeks stretched over to about 12 weeks. Thereafter, it showed a further jump to around 110 kg/man-day of eight hours after a job based incentive scheme with work measure as 100 kg steel fixing for first eight hours. Overtime at the rate of one hour for every subsequent 10 kg output was introduced, where workers got about two hoursof overtime on each working day though they physically worked for eight to nine hours per day.

14.1.6   Typical Causes of Low Labour Productivity

There can be many assignable causes for variations in actual productivity from the standard productivity. It is the moving average of actual productivity that indicates the extent of variations from

Exhibit 14.1

Labour Productivity Control Chart Steel Reinforcement
Fixing Output in Kilograms per 8-hour Man-day

Output kg/Man-day

Time in Weeks

Note: Output increased gradually after job-incentive schemes introduced in 4th Week.

the standard productivity. One of the causes of variations between actual and standard productivity may be due to the incorrect estimation of standard productivity. However, low productivity at the steady state level can be broadly attributed to the low morale of the workers, poor pre-work preparation by the supervisors, and the directional failure of t he project management.

a.   *Un-productive time*. It can be due to:

- Rework of defective work done;
- Waiting for material, equipment and/or instructions;
- Absence from work by workers;
- Other reasons;
- Frequent changes in the scope of work and work methodology; and
- Conflicts between supervisors and workers.

b.   *Workers' low morale*. This can result from:

- Non-fulfillment of employment terms and conditions by the management;
- Insecurity of employment;

- Sub-standard working conditions;
- Frequent transfers;
- Frequent changes in the scope of work and work methodology; and
- Conflicts between supervisors and workers.

c. ***Poor pre-work preparation by supervisors***. The lack of preparation for the execution of the assigned work prior to commencement can result in inefficient handling of resources due to:

- Excess workers employed for the task;
- Insufficient instructions for the execution of work; and
- Incorrect sequencing of work activities.

d. ***Directional failures of the project management***. These include:

- Failure to set performance targets;
- Failure to make provision for timely resource support;
- Failure to provide feedback; and
- Failure to motivate workers.

It is never feasible to eliminate all the causes resulting in low productivity. Mere increase of labour may result in increase in production but it may not necessarily improve productivity. Workers' productivity can be increased in many ways. Some of the typical down-to-earth approaches are given below:

- Reduce unproductive time by constantly reviewing and minimising causes contributing to unproductive time;
- Replace labour by appropriate equipment where economically feasible;
- Substitute inefficient working tools by appropriate efficient tools;
- Improve method of executing work remembering that there is always a better way of doing a task;
- Improve working conditions; and
- Employ competent supervisors.

Experience shows that most of the factors that affect the workers' productivity adversely can be minimised by good management following guidelines listed under the role of the construction manager in improving productivity.

The next stage of monitoring labour productivity is to forecast its trends for executing balance work. This is done by revising labour productivity (if required) by critically examining all the causes affecting low labour productivity, devising remedial measures to improve productivity, and evaluating the implications on existing productivity standards. The revised productivity standards can then be used to forecast the workers' requirements for balanced work.

It may be noted that it is not necessary to conduct analyses of labour productivity of all work-items or activities. Labour productivity analyses should be carried out on a selective basis only for those work-items or activities, which consume a major portion of the total manpower.

❏ 14.2   EQUIPMENT PRODUCTIVITY CONTROL

In construction, some tasks are labour-intensive, some predominantly employ equipment, and some use a combination of both, i.e. labour and equipment. While the actual work done and the associated labour is accounted for by the foreman concerned, the equipment productivity control is undertaken to determine its employment time, the output achieved, and its productivity at site. The main purpose of equipment productivity control is to minimise wastage in utilisation.

14.2.1   Accounting Equipment Productivity

In equipment productivity accounting, stress is laid on tracing the employment, time, operating expenditure and corresponding quantity of work accomplished for each major item of equipment. This accounting approach can enable a contractor to account for each equipment's expenditure as direct cost, and to evaluate its productivity.

The following paragraphs outline the basic approach for accounting the productivity of capital equipment. The method is similar to labour accounting. Two accounting documents of interest to the planning cell are the daily equipment employment account and weekly equipment productivity account. Generally data relating to daily employment time and operating expenses is recorded in the equipment log book.

Daily equipment employment accounting.   Equipment time-card is the basic document for accounting each equipment's employment time and the corresponding work performance. For each equipment, the time-card format generally follows the layout of the labour timecard, and each card can be suitably modified where necessary to meet the information requirement. Specimens of typical daily equipment employment cards are shown in **Table 14.4**.

This time card remains with the operator of the equipment, and it is filled up by the respective foreman/supervisor employing the equipment for work. The 'quantity of work executed' column provides important information for computing productivity data, and if quantity measurement takes time, the 'work-quantity' column can be filled up after the completion of activity by the respective foreman. Further for cycle-time calculation, if necessary, either the time-card can be modified or an additional suitably designed time-sheet can be used for collecting cycle-time data.

The daily equipment time-card, at the end of the work shift, is handed over by the equipment operator to the equipment cost centre. In particular, the fuel consumption is generally calculated by measuring the quantity needed to fill the fuel tank.

If the equipment starts work with full tank, then

$$\text{Fuel consumption} = \text{Additional fuel needed to fill the tank}$$
$$= \text{Fuel tank capacity} - \text{balance fuel in tank}$$

Weekly equipment productivity sheet.   The equipment productivity sheet shown in **Table 14.5** provides information about the actual productivity of each equipment for a given job. It shows

Table 14.4

Typical Daily Equipment Employment Card

Equipment No. _____	Operator _____		Date _____			
Type _____	Make and Model _____					
Working Time					**Total Employment Time**	**Unproductive Time (hr)**		
From	**To**	**Nature of Work**	**Qty.**	**Hours**		**Waiting Time**	**Repair Time**	**Misc Time**

1.   Engine Operating hours _____   Reading Start _____   End _____
2.   Received on date Fuel _____   Oil _____   Lubricant _____
in Litres
3.   Repairs carried out ____

the equipment's particulars, nature of work done, booking time, waiting time, repair time, and the serviceability condition of the equipment. The time lost when the equipment is not utilised is shown under waiting time of serviceable equipment, and under repair in case of breakdown of equipment at the site of work. The waiting time can be further subdivided into avoidable waiting time and unavoidable waiting time, and the reasons for waiting can be written on the reverse of the time-card. The equipment productivity can then be summarised, at the end of each week, in the form of the weekly equipment productivity sheet.

In order to make the construction site cost conscious, and to assess the unit rate for various items of work, the equipment utilised by the site can be charged by the equipment cost centre at a standard hourly rate. The usage cost accounting takes into consideration the owning and operating costs of each equipment. The details of these are covered in **Chapter 10**. These costs can be determined by maintaining the following records for each equipment in the Logbook and Daily Equipment Employement Card. The method of working out hourly owning and operating costs is given in **Chapter 10**. The records include:

- History sheet of equipment's major repairs;.
- Equipment's periodical maintenance record;
- Equipment's employment history since purchase and monthly operating hours and fuel consumption record;

Table 14.5

Weekly Equipment Productivity Report

S. No.	Equipment Particulars		Work Details		Pro-ductiv-ity Qty. + Hours	Time Account				
	No.	Type	Nature of Work	Qty.		Total (hr)	Work (hr)	Waiting (hr)	Repair (hr)	Misc. (hr)

- Operators' record; and
- Do's and don'ts for equipment operation.

It is stressed that the equipment productivity accounting and its costing need not be carried out for all pieces of equipment. Minor items of equipment like welding sets, compressors or even small capacity generators need not be accounted for while estimating the ownership costs. All such equipments are budgeted to last for the project duration. The ownership costs are distributed proportionately throughout the life of the project. It is only the major items of equipment having long life that are included for evaluation of hourly equipment performance cost.

The standard hourly rate can be reviewed once a month/quarter if necessary. Preferably, the standard hourly rate should be fixed close to no-profit-no-loss basis, so as to enable the accurate calculation of equipment unit cost for various items of work. The equipment operator hourly cost can be included in the standard equipment hourly cost or it can be accounted separately. In addition to controlling productivity, it is also necessary to keep an account of the serviceability, and utilisation time of each equipment, so as to optimise their use. The daily equipment employment schedule for this purpose can be prepared by the plant cost centre and it is distributed to all concerned at least a day prior to the date of utilisation. In case of equipments which operate under the instructions of

construction sites, the utilisation schedule is prepared by the site and a copy of this is given to the planning and plant cost centres so as to enable these centres to monitor equipment availability and performance.

14.2.2 Equipment Productivity Analysis

Generally, the equipment productivity at site differs from the standard productivity. In the initial stages, actual productivity is less than the standard productivity. It gradually improves provided the equipment remains in serviceable condition. However, the equipment performance depends upon many inherent variables. These include equipment serviceability condition, effect of terrain access to work site, working space restrictions, weather conditions, working conditions, work timings, logistic and equipment vendor support, and so on. Some of the controllable factors, which affect equipment productivity adversely, are as follows:

- Insufficient preparation;
- Lack of continuity of task;
- Inadequate operator's skill;
- Lack of effective supervision;
- Non-availability of maintenance, repair facilities and spares;.
- Poor equipment management, specially, lack of preventive maintenance measures; and
- Accidents.

Equipment productivity can be improved by suitably matching machines with the job, employing experienced operators and competent maintenance staff, adopting correct methods for work execution, employing serviceworthy machines, enforcing proper maintenance measures, and having an effective plant manager.

❑ 14.3   MATERIALS PRODUCTIVITY CONTROL

14.3.1 Materials Procurement Typical Checklist

The are two key aspects in monitoring of procurement of materials at the start of the project implementation. These are going through the materials procurement policy checklist and regularly updating of the materials procurement and monitoring sheet given in **Table 8.4** Section **8.3.6**. A typical checklist for materials procurement can include the following points:

1. Does the entity have a written policy for the procurement process?
2. Is the written policy sufficient and complete in all aspects?
3. Is the policy updated on a frequent basis?
4. Is there a proper requisition note with approval from the appropriate level of authority sent from he concerened department?
5. Does the entity raise an approval request for quotation (RFQ) within a reasonable time across various suppliers?

6. On receipt of various quotations, are there sufficient process to ensure that the right quotation is approved as regards quality, reliability, price and other factors?

7. On selection of the supplier, has an approved purchase order been placed with the supplier within reasonable time?

8. Are there sufficient controls to trace the purchase order and its status within the entity to ensure receipt of materials without delay?

9. Does the entity ensure penal clauses in case of delay receipt of critical material to ensure timely supply?

10. Are there any contracts entered by the entity with suppliers for critical materials to ensure adequate supply at a reasonable price?

11. Are there sufficient procedures to inspect materials with regard to specification and quantity, received by the entity at the site before unloading and signing of the delivery note?

12. Are there sufficient documentary controls such as Gate Pass for entry of goods?

13. Has a sample check for compliance of procedures performed?

14. Is the process of receipt of materials properly co-ordinated with the Finance department to ensure proper accounting?

15. Does the materials receiving department maintain sufficient record of receipts and inspection of material?

16. Has the delivery note been approved by the appropriate level of authority before making the entry?

17. In case where materials are supplied by client, has the internal auditor ensured that the there has been appropriate accounting of such material?

18. Does the entity have proper control for materials received from the client? Are they separately identified and demarcated?

19. In case of critical materials or slow moving materials, does the entity transfer the materials from one site to another rather than purchasing them from external sources?

14.3.2 Accounting for Construction Materials

Materials accounting system documents the materials data. It provides the materials procurement status. It shows the holding of materials inventory for the incoming works. It identifies and quantifies issues of materials to the site and it reveals the materials costs. Project planners are specially concerned with materials-flow data for ensuring the timely procurement of materials, and site availability of materials of right quantity and quality at the required time and place. It aims at minimising wastage during usage, evaluating implications of variationfrom the acceptable wastage standard, updating cost estimates and expenditure of materials, and formulating materials costing norms for future works.

The materials accounting process from demand initiation till its consumption stage involves maintenance of up-to-date records of receipts and issues at the project central store, monthly stock checking of materials in the store and at the work site, and the return of the unused materials after completion of the intended job.

14.3.3   Materials Stock Accounting

Stock accounting is the clerical process of recording the movement of materials in and out of the stores. The basis of stock accounting method is a stock record card (also called bin card), which provides an up-to-date record of the stock of materials. The stock record card (specimen shown in **Table 14.6**) is the main source of information on the availability of materials and other connected data. A suitably designed stock record card can show stock code, description, unit of specification, stock location, stock levels (i.e. minimum, maximum and re-order levels), source of supply, lead time for procurement, sequential, data-wise record of receipt and issue quantities, balances at any point of time and other connected information as required. In particular, the stock levels set on the stock record card regulate the inflow and the outflow of materials, and sound a timely warning for commencing stock replenishment.

Table 14.6

Typical Materials Stock Control Bin Card

Code No. __   Bin No. _____

Description _____   Stores Ledger No. _____

| Date | Receipts | | Issues | | Stock Balance |
	GRN No.	Qty.	REQ No.	Qty.	Qty.
	Balance BIF				

A bin card shows level of stock of an item in a bin at a particular store location. It serves many purposes such as:

a. Materials of the right quantity and quality are available in the stores at the right time.
b. The stock levels are kept as low as feasible to minimise investment or inventory holding costs on the materials and to avoid occupying of excessive storage space resulting in high overheads.
c. Stock quantities can be easily verified thus preventing pilfering, theft and wastage.

On the whole, the stock record card if properly maintained, can serve as the main source of information on materials to the materials department, planning department, costing department and finance accounting department.

14.3.4 Materials Issues and Returns Accounting

The construction materials are obtained by the construction supervisors from the project control stores, or the materials are directly delivered at the place of work. In both cases, the construction supervisors, on behalf of the construction manager, sends a materials requisition note for the materials required by him to the project central store. The specimen of the materials requisition note is shown in **Table 14.7**. The store in-charge on the authority of this note issues these materials. In case of non-availability of materials in the project central store, the store in-charge passes this note to the materials controller for procurement and delivery at the central stores or at the place of work.

If the materials are delivered directly at the construction site, a goods received note (GRN) is signed by the site supervisor receiving the materials, and the GRN duly signed is sent by him to the project materials controller for accounting and payment through the accounting department.

Table 14.7

Typical Materials Requisition and Issue Control

Materials Requisition and Issue Note

Responsibility Centre					
Name			Centre Code		
Work Package/Activity					
Description			Code		
S. No.	Materials		Unit	Quantity	
	Code	Nomenclature		Required	Issued
Indenting Supervisor			Issuing Storekeeper		
Date and Signature			Date and Signature		

Generally, there is a tendency on the part of the site supervisors to demand more materials than required for avoiding the risk of shortage at the time of execution. The surplus materials are eventually either returned along with the materials return note specimen shown in **Table 14.8** or they get wasted at the site.

14.3.5 Monthly Stock Taking of Selected Materials

Stock taking is the process of accounting physically the stock-in-hand and verifying this with the balance shown in materials accounting document at predetermined intervals (see **Table 14.9**). The monthly stock taking enables cost evaluation of materials for billing the materials-at-site advance, costing materials inventory, and controlling materials mobilisation status, and reconciling stock discrepancies. Possible causes of discrepancies between physical stock and storekeeper's records can be due to the following:

Table 14.8

Typical Materials Return Note

Materials Return Note:

Responsibility Centre				
Name		**Centre Code**		
S. No.	**Item Code**	**Description**	**Quantity**	**Remarks**

Returning Supervisor
Date and Signature

Receiving Storekeeper
Date and Signature

Table 14.9

*Typical Stores Accounting Ledger Sheet

	Ordered		Receipts		Issues		Stock Balance	Ordered Qty.
Date	**S.O. No.**	**Qty.**	**GRN No.**	**Qty.**	**Req. No.**	**Qty.**	**Qty.**	

Code No.   Max Stock Level
Description   Min Stock Level
Location   Re-order Level
Quantity Required   Re-order Quantity

- Materials received of different types and qualities than those shown on goods received notes (GRN) and site materials requisition notes (REQ);
- Quantity of stock issued to construction centre is different than the quantity shown on the requisition note;
- Surplus materials held in the construction centres are transferred or returned without documentation;
- Breakages, damages and losses at the construction centres are not accounted for during stock taking; and
- Clerical errors in accounting.

The discrepancies are reconciled every month or quarter, and the adjustments are made in materials cost, or these are written off from the profit and loss account.

14.3.6   Materials Wastage Analysis

Wastage of materials can take place during the procurement process, storage, and during utilisation. Wastage during procurement can result from one or more of the following main causes:

- Buying materials of wrong specifications;.
- Buying more than the actual requirements;
- Unnecessary buying of items to cater for unrealistic and unforeseen eventualities;
- Untimely buying of short-lived materials;.
- Improper and unnecessary handling of materials; and
- Wastage in transportation.

Wastage during operating and storage can occur due to the followings reasons:

- Damages and breakages during handling; and
- Deterioration due to incorrect storage, incorrect maintenance, short-shelf life, losses due to fire and thefts and exposure to extreme climatic conditions.

Some unavoidable wastage is inherent during utilisation, but it is the excessive wastage, which is of concern to the management. Excessive wastage during the utilisation stage affects the productivity adversely and consequently results in extra costs. Productivity control aims at minimising wastage in usage. Productivity control at the construction responsibility centre level can be broadly divided into accounting for materials, analysing usage variances to determine the causes of wastage and implementing measures to minimise wastage.

The first step in materials wastage analysis is to quantify standard quantity and type of direct materials needed for each work item. The actual materials consumed for each work-item can be complied from the material issues and return notes transacted between supervisors and stockholders. In case of materials delivered directly to the construction site by the supplier, such as ready-mix concrete from site, batching plant or fabricated steel for reinforcement from the site steel yard, or aggregate from a crusher, the supplier's delivery note along with the materials' return note (if any) can be used to determine the quantity consumed for a given work-item. The issue slips and

delivery notes, when consolidated from the start to completion of the work-item/activity can give an estimate of the quantity of materials consumed. The difference between the standard materials' requirement and materials actually consumed indicates the excess (if any) from the accepted materials wastage standard prepared at the time of estimation.

$$\text{Materials usage variance} = \text{Standard acceptable materials wastage}$$
$$- \text{Actual materials wastage.}$$

Causes of Excessive Wastage.   The main reasons for excessive materials wastage during usage can be attributed to one or more of the following:

- Excess-quantity estimation;
- Shortage in delivery;
- Theft and pilferage;
- Breakages and damages during handling;
- Lack of pre-work preparation and coordination;.
- Inferior quality of materials;
- Improper accounting and poor storekeeping;
- Negligent and careless attitude of the supervisor;
- Unforeseen circumstances like accidents, fire, etc.;
- High rate of deterioration due to long storage at the place of work; and
- Over-issues from the central stores and failures to return unused surplus materials.

Some of the preventive measures to minimise wastage include the use of proper handling and transportation of equipment, minimising unnecessary shifting, setting up of proper and secure storage areas, correct accounting of materials, fire precautions, improvement in the process of construction, and the education and training of staff and workers to ensure productivity improvement.

❑ 14.4.   GUIDELINES TO SAFEGUARD WORKERS SAFETY, HEALTH AND PROTECTION OF ENVIRONMENT

14.4.1   Need for Workers' Safety

Construction involves risky operations in dangerous areas, such as working at heights, working on slippery surfaces and working under material handling equipment. Constantly changing sites, nature of work, construction methodology and technology to add new dimension to the safety problems. Safety is a question of life and death for those working at construction sites. In its broader sense, safety at construction sites implies freedom from danger of risks of injury due to accidents and danger to health resulting from occupational hazards. High accidents rates and/or high exposure to health hazards mean poor safety and vice versa.

Unsafe work site and unsafe work behaviour leads to accidents. An accident is an unplanned, unwanted, undesirable, sudden mishap which interrupts an activity or a function; and causes suf-

ferings and/or damages. Accidents do not just happen, they are caused. A cause of the accident is an uncontrolled hazard. The worst sufferer due to an accident is the worker. These accidental unintentional unsafe acts result in loss of life, limb, time and money. A worker who meets with an accident suffers from financial, physical and mental loss, and he could be the sole bread earner. These accidents add to avoidable death toll and crippled human population. No amount of money can compensate for the lost life, lost limb or lost time of the family bread earner. These permanent damages to the life of a worker can be avoided.

Safety of workers comes first always and every time. Every job can be done safely. Safety awareness saves accidents. Accidents multiply worries, miseries and costs. Controlling accidents reduce the saddest product—human scrap. Safety is everyone's responsibility; we must take pride in accident prevention. Time, money and efforts spent on safety always pay dividend. Safety adds to corporate reputation. Safety serves society and safety is the builder's first responsibility. Most profitable companies in the world have most impressive safety performance. It is the responsibility of all concerned with construction to prevent accidents by creating safety awareness.

Employers do face serious economic consequences of avoiding accidents and health hazards. The employer's monetary cost of such consequences represents the replaceable cost of losses. These losses include reduced output, wasted wages, lost time, lowered morale, damaged property, loss of experienced hands, replacement, insurance cost and incidental expenses such as statutory reporting, investigations, medical aids, additional office expenses and work breakdown till restarting of the activity. The accidents and the unhealthy environments eat away the employer's profits. Accidents subtract employer's pleasure, add to the employer's miseries, divide employer's income and multiply employer's worries. Studies reveal that employer's safety measures save money.

Safety management at construction sites aims at minimising casualties and damage to manpower by ensuring safe working environment through well-planned safety policy, organised enforcement of safety measures, and creating safety awareness through education and training.

14.4.2   Fatal Injuries in Construction Industry

Construction is the most dangerous land-based work sector, after the fishing industry (see **Table 14.10**).

In Britain, construction site reported data from 1985 to 1994 reveals that due to accidents and other hazards at site, out of every 100 000 construction employee, annually on average 10 employees died and about 200 suffered major injuries (see **Table 14.11**). In addition, roughly 20 times more workers suffered minor injuries sufficient to keep them off work for three days. Further the average rate of fatal injuries in construction is around 5 times higher than that of manufacturing industry.

In the USA there were 1225 fatal occupational injuries in the construction sector in 2001 with an incidence rate of 13.3 per 100 000 employed workers. In 2009, the fatal occupational injury rate among construction workers in the United States was nearly three times that for all workers.

Table 14.10

Fatal Injuries per 1000 Construction Employees

Country	1976	1980	1985
German	0.1	0.1	0.1
Japan	0.3	0.1	0.0
Korea	0.5	0.4	0.5
Singapore	0.3	0.0	0.0
U.K.	0.1	0.1	0.1 (1984)
U.S.A.	0.1	0.1	0.1 (1984)

Source: Table 17 General Reports ILO 1987
(Building, Civil Works and Public Works Committees Report)t

Table 14.11

Fatal and Major Injuries per 100 000 Construction Employees

	1986	1987	1988	1989	1990	1991	1992	1993	1994
Fatal injury									
Construction industry	10.2	10.3	9.8	9.4	9.3	8.8	8.0	8.4	6.2
Manufacturing industry	2.1	1.9	1.8	2.1	1.8	1.5	1.5	1.6	1.1
Majore injury									
Construction industry	282	276	282	299	286	272	239	208	211
Manufacturing industry	145	142	141	144	136	129	124	126	125

Source: UK Health and Safety Executive Report.

14.4.3 Causes of Accidents

Main causes of accidents can be analysed from the data reported by some of the construction organisations and the statistics released by the statutory bodies. In one of the studies extending over two years covering 45 000 workers in a public sector construction company, in power plants, the causes of reported accident were as under:

The studies on the safety of persons at work site reveal the following:

1. The basic causes of accidents in civil engineering works in the order of seriousness are as follows:

   - Persons/Materials falling from height;
   - Persons being struck or trapped by moving objects;
   - Persons stepping on or striking against objects;

Persons handling objects in such a way so as to cause injury e.g. using equipment without having received proper training in its use;

A Reputed Public Sector Construction Company Actuals		
S. No.	**Causes of Injuries and Fatalities**	**Percentage**
1.	Fall of persons from height	48%
2.	Vehicles	14%
3.	Fall of objects from height	11%
4.	Electrocution	6%
5.	Collapse of excavation/structures	8%
6.	Pressed under loads	6%
7.	Others	7%

- Persons using improper hand tools;
- Failing to use the appropriate equipment;
- Distracting others from their work or allowing yourself to be distracted; and
- Other causes.

2. There is an increase in the frequency of accidents in case of new employees specially during the first year of service.
3. In industrialised countries, the average number of fatalities per 100 000 workers are around 12, with some countries reporting 35 deaths per 100 000 workers. In India, one of the reputed company has recorded the death rate of around 100 per 100 000 workers.
4. The accident rate in construction is 4–5 times higher than that of the manufacturing sector on the global scale .

Further, workplace accidents occur for many reasons. Below are some of the unsafe workplace behaviors that can lead to accidents:

a. Taking Shortcuts: Shortcuts that reduce job safety are not shortcuts at all, but an increased risk of injury.
b. Being Over Confident: Too much confidence in one's work ability can lead to improper procedures, tool mishandling etc., which could lead to an accident.
c. Beginning a Task with Incomplete Instructions: To perform a job safely and correctly, require complete information.
d. Poor Housekeeping: Poor housekeeping creates hazards of all types. Cleanliness is usually an accurate indicator of everyone's attitude about quality, production and safet.
e. Ignoring Safety Procedures: Purposely ignoring known safety procedures can endanger not only you but your co-workers too. Being indifferent about safety is a death wish.
f. Mental Distractions: Dropping mental awareness can pull focus away from safe work procedures.

g. Failure to Plan: Hurriedly starting a task, or not thoroughly thinking through the process.

14.4.4   Causes of Occupational Health Hazards

Construction Workers are exposed to a wide variety of health hazards on the job. Such exposure differs from trade to trade as also from job to job on a day-to-day and even on an hourly basis. Exposure to any one hazards is typically intermittent and of short duration, but is likely to recur. The severity of each hazard depends on the concentration and duration of exposure to a particular job. Construction hazards are divided into four classes:

- Physical hazards,
- Chemical hazards,
- Biological hazards and
- Social hazards.

Physical Hazards

a. Construction workers are exposed to physical hazards such as noise, heat and cold, radiation, vibration and barometric pressure.
b. Noise is produced by the activity like demolition, engines of all kinds of vehicles and machines operating in construction sites.
c. Vibration is generated due to pneumatic hammers, hand tools and earth moving and other large mobile machines.
d. Heat and cold hazards arise primarily because work is conducted while exposed to the weather. Roofers are exposed to the sun with no protection.
e. The principal source of non ionising ultraviolet radiation is the sun sin and electric arc welding.
f. Those who work under water or in pressurised tunnels or in caissons are exposed to high barometric pressure. Such workers are at a risk of developing a variety of conditions associated with high pressure, decompression sickness, inert gas narcosis, aseptic bone necrosis and other disorders.
g. Oxygen deficiency may occur in tunnels either because oxygen is displaced by other gases or because it is consumed by microbes or by the oxidation of pyrites.
h. Strains and sprains are quite common among construction workers. Fall due to unstable footing, unguarded holes and slips off scaffolding and ladders are very common.
i. Electrical and Mechanical Hazards such as, improper cabling, open joints, insulation, damaged or broken cover, gas welding etc.

Chemical Hazards

Chemical Hazards are often airborne and appear as dust, fume, mist, vapour or gas; thus exposure usually occurs by inhalation, although some air borne hazards may settle on and be absorbed through the intact skin (e.g. pesticides and some other organic solvents). Several illnesses have been linked to the following categories of construction workers:

- Silicosis, a disease of lungs, among sand blaster, tunnel builders and rock drill operators;
- Asbestosis (and other diseases caused by asbestos) among insulation workers, steam pipe fitters, building demolition workers and others;

- Bronchitis among welders;.
- Skin allergies among masons and other who work with cement;
- Cement dust is generated when cement is mixed. The dust is a respiratory and mucous membrane irritant in high concentration. When it settles on the skin and mixes with sweat, however, cement dust can cause dermatitis;
- Neurological disorders among painters and other exposed to organic solvent and lead; and
- Elevated death rates from cancer of the lung and respiratory tree have been found among asbestos insulation workers, roofers, welders and some wood workers.

Biological Hazards

a. Biological hazards are exposure to infectious micro-organisms, to toxic substances of biological origin or animal attack.
b. Excavation workers can develop histo-plasmosis which is an infection of lungs caused by a common soil fungus.
c. Workers may also be exposed to risk of malaria, yellow fever or lyme disease in areas where organisms and their insect vectors are prevalent.

Social Hazards

a. Since the work force is constantly changing and many projects require living in work campus away from home and family, construction workers generally lack stable and dependable network of social support. Migration under economic compulsion from one part of the territory of India to another causes dislocation of home life including educational deprivation of children. It has generally been observed that the whole family i.e. husband, wife and children moves and as they move and land at a destination, they are exposed to new stresse and strain on account of changes in climate, language, socio-culture customs and practices and such changes is generally to the detriment of interests of migrant families.
b. Construction projects are known to impact environmental deterioration. Noise, vibration and dust particles are known as major public nuisances during construction. The noise, vibration, building settlement, ground settlement; topographical change, water (surface/ground) contamination and drought problems have a direct impact on the environment.
c. The workers are exposed to crystalline, silica dust, cement dust, noise, vibration, diesel engine exhaust, chemical vapour, random and oxygen deficient atmosphere during underground construction work such as tunneling for roads, highways and rail roads, laying pipelines for sewers, hot water, steam, electrical conduits and telephone lines. Underground workers are at risk for serious and often fatal injuries.

Risks assessment of non-conformance of health and safety hazards.   The object of risk assessment is to foresee hazards, evaluate risk, and mitigate risks using preventive measures during execution to minimise impact. Thereafter, develop risk response plan to counter the impact of these hazards in the evantuality of their occurences. (Refer to risk management in **Chapter 17.**)

14.4.5   Project Environment Management System

In the project context, the environment management focuses on pollution control and prevention including sustaining development. Pollution prevention involves identifying activities that can result in adverse environment impact, evaluate adverse impact using qualitative and quantitative tools and control these impacts to reduce adverse ecological, social and economic aspects specially on air, water, soil, climate, flora and fauna, people, material and equipment wastage. Sustainability of development aims at meeting the needs of the project without compromising the needs of the future generation.

Environment Management System is a planned and co-ordinated set of management actions, operating procedures, and record-keeping documentation, implemented by a specific organisational structure with defined responsibilities, accountabilities and resources. It aims at the prevention of adverse environmental effects as well as the promotion of action and activities that minimise/sustain environmental quality.

ISO 14000: Environment Management Systems Series include:

- 14001 Series: Environment management systems;
- 14010 Series: Environmental auditing;
- 14020 Series: Environmental labeling;
- 14030 Series: Environmental performance evaluation;
- 14040 Series: LCA principles and practices; and
- 14050 Series: Environmental management terms and definitions.

An Environment Management System (EMS), therefore, is intended to link the various processes through a network of management actions, procedures, documentation and records, with the aim to:

- Identify and control significant environmental vulnerabilities and effects;
- Identify significant environmental opportunities;
- Identify relevant environmental regulatory requirements;
- Establish a sound environmental policy and basis for environmental management;
- Establish priorities, determine objectives and work towards their achievement; and
- Monitor performance and evaluate the effectiveness of the system, including promotion of system improvements and adaptation to meet new and changing conditions and demands.

Mandatory procedures required by ISO-14001 are:

- Identification of environmental aspects;

- Identification of and access to legal requirements;
- Training, awareness and competence;
- Internal and external communication;
- Document control;
- Operational control;
- Emergency preparedness and response;
- Monitoring and measurement;
- Evaluation of regulatory and legislative compliance to environment;
- Non-conformances and corrective and preventive actions;
- Control of records; and
- EMS audit.

Specifically, an Environmental Management System is intended to help the project management to:

a. Identify and control the environmental aspects, impacts and risks relevant to the organisation
b. Achieve its environmental policy, objectives and targets, including compliance with environmental legislation
c. Define a basic set of principles that guide your organisation's approach to its environmental responsibilities in the future.
d. Establish short, medium, and long-term goals for environmental performance, making sure to balance costs and benefitsfor the organisation and its various shareholders and stakeholders.
e. Determine what resources are needed to achieve those goals, assign responsibility for them and commit the necessary resources.
g. Define and document specific tasks, responsibilities, authorities and procedures to ensure that every employee acts in the course of their daily work to help minimise or eliminate the enterprise's negative impact on the environment.
g. Communicate these throughout the organisation, and train people to effectively fulfill their responsibilities.
h. Measure performance against pre-agreed standards and goals and modify the approach as necessary for workers' Safety

14.4.6   Health and Safety Mandatory Statutory Requirements

Almost all the countries in the world have enacted regulations to safeguard construction workers' Safety, Health and Environments (SHE). In India, the Building and Other Construction Workers (Regulation of Employment and Condition of Services) Act 1996 and Central Rule, 1998 and State Rules, cover the statutory measures to be ensured by employer to ensure safety of workers at construction sites. According to the Building and Other Construction Workers (Regulation of Employment and Conditions of Service) Act, 1996 and Central Rules, 1998, the employer has the sole responsibility for ensuring safety of construction workers. The statutory requirements are generally included in the contract documents and form a part of good construction practices.

OHSAS 18000 is an international occupational health and safety management system specification. It comprises two parts, 18001 and 18002. OHSAS 18001 was created via concerted efforts from a number of the world's leading national standards bodies, certification bodies, and specialist consultancies.

An effective accident prevention program is the best guarantee against the accidents. Time, money and efforts spent on safety always pays dividends. Safety and efficiency go hand in hand. Safe practices yield high productivity, boost workers morale, project corporate image, cut accident costs and ensure compliance with the law. The studies highlight that it is economical to enforce safety measures at construction sites rather than face the consequences of unsafe project environments.

❑ 14.5   ROLE AND FUNCTIONS OF CONSTRUCTION MANAGERS IN IM PROVING RESOURCES PRODUCTIVITY

14.5.1   Role of the Construction Manager

Productivity control is the primary function of the manager employing the resources. The planning cell assists the manager in exercising productivity control. There can be many assignable causes for variations in actual productivity from the standard productivity. But low productivity can be mainly attributed to poor pre-work preparation by supervisors, low morale of the workers and the directional failures of the project management. The manager can improve resources productivity by setting targets, ensuring pre-work preparation and coordination, monitoring performance, and motivating the work force. It is the leadership qualities of the manager that makes all the difference.

It is the dynamic leadership of the Project Manager and the Construction Manager, which greatly influences the supervisors and the work force.

14.5.2   Productivity Related Functions of the Construction Manager

The construction manager can play the most vital lead role in achieving the project goals by performing the following functions effectively and efficiently, these functions are detailed in the following sub-sections:

- Envisioning the task ahead;
- Enabling the individuals to perform the task systematically and efficiently;
- Setting targets and monitoring performance;
- Providing resources support;
- Implementing a sound incentive scheme;
- Communicating feedback;
- Motivating the work force;
- Building the line supervisors team;
- Creating safe working environments;
- Abiding by Professional ethics; and

- Leadership makes all the difference.

Envisioning the task ahead.   A vision describes the long term view of the task ahead and how the organisation intends to fulfil it. It includes:

- Knowing the value systems of the organisation and the project stakeholders;
- Understanding the objectives, planning, execution and controlling processes of both the project and the product;
- Chartering and tracking the road map for accomplishing the assigned tasks to the full satisfaction of the project manager and the client;
- Leading the own taskforce efficiently and effectively; and
- Creating favourable environment in the task force for continually improving the quality of its project management process.

Enabling the individuals to perform the task systematically and efficiently.   It aims at developing the full potential of individuals by:

- Design the training to perform the contemplated task and to fit into the jobsite conditions;
- Fit the crew staffing to the tasks;
- Tell people exactly what is expected of them;
- Show people how to perform well; and
- Keep the work force informed as to progress against schedule.

Setting targets and monitoring performance.   This process includes:

- Planning the work well ahead and keeping all concerned informed about the work;
- Enabling the supervisors to participate in setting the future weekly targets, understand the method of their accomplishment, know the resources standards specified for achieving these targets and are aware of the plans, specifications and the construction methodology;
- Ensuring that all workers know their job-oriented productivity standards and the connected incentive schemes and the supervisors prepare and conduct briefings to workers a day prior to the day of starting the activity;
- Ensuring that the project planning team is effectively monitoring the performance of the resources and is getting cooperation from all concerned; nad
- Avoiding changes to the plans as the work progresses.

Providing resource support.   It involves ensuring that:

1. Materials in the right quantity and quality from the right source are ordered and their supply is closely followed up so that the materials are delivered to the sites at the right time. In the case of anticipated delays in deliveries, the work plans are rescheduled well in time and all concerned are informed accordingly.
2. The suitable manpower is identified in time and it possesses the right skills and experience needed to perform the job.

3. The type and capacity of the equipment and tools provided at the work site can perform the task assignedif the equipment operators possess the necessary skills, that there is necessary maintenance support and preventive maintenance is carried out.

Implementing a financial incentive scheme. The primary purpose of a financial incentive plan is to motivate the worker to increase productivity by producing more to secure a high wage while at the same time affecting savings in production cost per unit. This subject is coverd in **Appendix G**. A financial incentive scheme should be:

- Simple enough, so that the workers can easily comprehend it;
- Specific enough, so that the output can be measured without any controversy;
- Concise enough, so that the unforeseen and unavoidable hold-ups in work progress can be easily determined and workers can be compensated for the time wasted during execution;
- Attainable enough, so that the workers find prospects of higher earning than their guaranteed minimum wages.
- Supervised enough, so that work progresses smoothly as per standard engineering practices and quality specifications; nad
- Comprehensive enough, so that all the statutory requirements are fulfilled.

An incentive scheme needs to be designed carefully. It is difficult to promote to workers. It faces teething problems during implementation. Once implemented, it cannot be altered without the concurrence of the affected workers. With all its drawbacks, however, an incentive scheme is still necessary to motivate workers to give their best. In conclusion, it can be said that workers work harder if there is a financial reward linked to their performance and the management saves upon time and costs if it is properly implemented.

Communicating feedback.   Supervisors and workers need frequent feedback to know as to how well people perform. It involves:

1. Frequent (almost daily) on the job meetings with supervisors to review the actual progress against targets of the current week, and analysis of the causes for variance from the planned progress and standards.
2. Weekly review meeting with the supervisors to communicate detailed information on job progress of the previous week, resource productivity achieved, causes for changes in productivity and the expected target and productivity for the coming week.

Motivating the work force.   The various measures include:

1. The personnel policies are well formulated and properly implemented so that workers get what they are assured according to the terms and conditions of employment, in particular, their salaries and wages are given on time.
2. The performance of supervisors who perform well is acknowledged.
3. The engineers, supervisors and workers feel that they are making a valuable contribution in handling challenging tasks assigned to them.

4. Good performance is rewarded by providing non-monetary recognition, giving monetary benefits through job-related incentive schemes and other morale-raising and work-motivating measures.

Building the line supervisors team.   Line managers and supervisors are the key leaders at the operating level. They are a vital link for motivating skilled and unskilled workers. This team building involves:

- Create the supportive environments for building the team;
- Assign identity to each team and set its goals;
- Model the team norms;
- Facilitate team working;
- Design programme to upgrade cooperation and skills within the team;
- Lead through team-work rather than individuals; and
- Select supervisors who can fit in as the team member.

Creating safe working environments.   Safety comes first, always and every time. It is the duty of the the managers, supervisors and the worker to ensure that the safety rules and security measures formulated are properly enforced to prevent accidents and pilferage. Further workers must be protected against the adverse weather conditions and environmental health hazards to minimise the health risks. Safety provisions are covered in **Chapter 13**.

Abiding by professional ethics.   Ethics are moral principles governing or influencing the conduct of a person, religious group or profession. Moral principles distinguish between right and wrong in conduct or behaviour. Ethics give rise to a set of values. Organisations, through their Code of Ethics define the ethical values and support these with rules or guidelines to direct their members so that they conform to these values in professional dealings and decision-making. Construction Manager should act in such a manner as to uphold and enhance the honour, integrity and the dignity of the country, organisation and profession. Engineers must respect the duties of the citizen as enshrined in the constitution of the country; and encourage associates, colleagues and co-workers to act in conformity with the following value system:

1. Social Responsibility to Uphold Ethical Values of the Society:

   a. *Public safety*: Ensure safety, health and welfare of the public in the performance of their professional duties. Safety of the people must always come first. They should promptly disclose to all concerned the factors that might endanger public safety or the environment.
   b. *Compliance with social order*: Abide by the laws of the land in which the work is performed, respect the local customs, uphold human rights, safeguard public property and abjure violence and acts of terrorism.
   c. *Impartiality and fairness*: Treat fairly all persons regardless of such factors as race, caste, religion, state, gender or national origin.

d. *Environment protection and improvement*: Strive to maintain clean, healthy and safe environments and comply with the statutory requirements.

e. *Environment safeguards*: Disclose any factor that endangers the environment.

2. Responsibility to maintain high standards of professional quality. These professionalresponsibilities include the following:

a. *Development of technical and managerial skills*: Maintain state-of-the-art professional skills, continue professional development and provide opportunity for the professional development of those working under their command.

b. *Undertake assignments where professionally competent*: Perform service only in the area of their technical competence or after full disclosure to their employers or clients of their own limitations.

c. *Performance responsibility*: Seek work through fair and proper methods and shall take full responsibility for the task undertaken by them.

d. *Proper verification of documents and production processes*: Approve only those designs, which safely and economically meet the requirement of the client and shall not approve any engineering document, design, materials, stages of work which they consider it to be unsound.

3. Obligation to maintain high standards of personal behaviour in the following responsible manners:

- *Honesty and integrity in professional dealing*. Maintain a high degree of honesty and personal integrity in all their professional dealings. They shall not accept or give bribes in any form;
- Compensation for services rendered;
- Do not engage in unhealthy competition;
- *Professional opinion*. Seek and offer honest criticism of technical work, acknowledge errors and give credit properly for the contribution of others. Where necessary, engineers shall issue public statements in an objective and truthful manner;
- *Professional relationship with the employer*. Act faithfully as trustee of the employer/client on professional matters;
- *Information communication with employers*. Keep the employer and client fully informed on all matters relating to progress of business including financial aspects, which may affect the assigned work;
- *Mutual obligation and trust*. Do not, maliciously or falsely, injure the professional reputation of another engineer or organisation;
- *Self promotion*. Build reputation based on merit, service to the customers and shall not falsify or misrepresent their contribution;
- *Employers' business secrets*. Do not disclose by any means, confidential information of the employer or client, unless otherwise authorised; and

- *Personal conflict*. Disclose real or perceived conflicts of interest to affected parties and avoid these where possible.

Leadership makes all the difference.   In generic terms, leadership is the art of influencing work groups to achieve the mission. Leader is a person responsible for achieving objectives through his team that works enthusiastically and willingly.

Leading the organisation entails defining goals; motivating individuals and teams committed to do their best, all working together enthusiastically and willfully with the ultimate aim of delivering products and services that satisfy the customer.

Project leaders must avoid the common pitfalls that derail a leader. These include:

- Rigid, abrasive and arrogant style of functioning;
- Over ambition and playing politics;
- Failure to handle performance problems on time;
- Unwilling to delegate responsibilities and over managing specialist technical tasks;
- Unable to build a work-team;
- Over dependence on superior and mentors; and
- Betrayal of trust and failure to meet commitments.

Studies carried out recently by Fortune 500 reveal that the most important character trait that correlates with goal achievement is truthfulness (honesty). Truthfulness and honesty are essential to leadership competence and form the foundation of trusting relationships between leaders and followers.

If there is one single attribute of a leader , which should be regarded as absolutely essential, it is that of commitment to the project's success. Without this, other personal attributes, no matter how admirable, will not necessarily benefit the project.

APPENDIX N

Typical Health, Safety and Environment Audit Checklist for Construction Projects

These should be supplemented with the Building and other Construction Workers (Regulation of Employment and Conditions of Service) Act, 1996/ Rules, 1998 and Project Specific Safeguards

❑ N.1 CONTRACTORS HSE ADMINISTRATION

N.1.1 HSE Organisation

- Check the adequacy of HSE personnel.
- Are HSE personnel professionally qualified?
- Has the employer approved each HSE personnel?
- Does the HSE manager report to the Project Manager?
- Can HSE personnel stop any unsafe act?

N.1.2 HSE Committee

- Is site HSE committee formed?
- Is Project Manager (PM) Chairman of HSE Committee?
- Does construction HSE Committee meet at least weekly?
- Does project HSE committee meet at least monthly?
- Are Incidents Reports discussed?

N.1.3 ID-card and First Day at Work

- Is ID card issued to all persons?

- Is ID card as per Client standard?
- Has an authorised officer signed all ID Cards?
- Have all workers undergone orientation/ induction training?
- Is HSE manual held at the site office?

N.1.4 HSE Submittals to Employer

- Daily Reporting of workmen;
- Monthly HSE report;
- HSE Committee meeting minutes;
- HSE Inspection Report; and
- Monthly internal HSE audit Score Report.

N.1.5 Visitors to Site

- Does visitor get the permission from employer?
- Is contractor issuing PPE to visitors?
- Is the visitor escorted by a responsible person?
- Are visitors entering hazardous area protected?
- Is visitor register maintained at site office?

N.1.6 Induction Training

- Does training take place in the first week?
- Is there Induction Handout?
- Is training related to task?
- Is Management participating in training?
- Is attendance record kept?

N.1.7 Toolbox Talks

- Are they held at least weekly?
- Are they presented by the supervisor/safety officer?
- Is System monitored by Management?
- Are all appropriate employees involved?
- Is Attendance Record kept?

❑ N.2 HSE TRAINING AND COMMUNICATION

N.2.1 Training Policy

- Is Training Policy in HSE Plan?
- Is Policy implemented?
- Does it include sub-contractors?
- Is Training Policy published?
- Does PM understand Training Policy?

N.2.2 HSE Signage

- Is signage in correct colours?
- Are adequate numbers of signs?
- Are signs suitably positioned?
- Are signs in Hindi and English?
- Is signage being maintained regularly?

N.2.3 HSE Posters

- Are posters in adequate numbers?
- Are posters separately numbered?
- Do posters cover all topics?
- Are safety posters visible on site?
- Are posters being maintained regularly?

❑ N.3 HSE INSPECTION AND AUDIT

N.3.1 Planned General Inspection

- Is monthly contractor and sub-contractors site HSE inspection done?
- Is weekly HSE inspection by supervisors done?
- Is Daily HSE inspection by site HSE team done?
- Are Employer's and contractor's representative involved in this HSE inspection?
- Are Records maintenance?

N.3.2 Are Specific Inspection Done

- Before a heavy lifting operation?
- Before and after entry into confined space?
- Before and after a welding and gas cutting?
- Before concreting form work?
- All high-risk processes inspected by competent supervisor?

N.3.3 Are Routine Inspections Done

- Operator Daily Inspection of Plant and equipment;
- Monthly inspection of electrical hand tools;
- Quarterly inspection of temporary electrical system;
- Weekly inspection of scaffold by scaffolding supervisor; and
- Half yearly inspection of lifting appliances and gears by competent person.

N.3.4   HSE Inspection

- Has Contractor prepare checklist for all activity?
- Is the check list mentioned in Contractor HSE plan?
- Are all inspection reports documented?
- Are Inspection reports sent to Chief Security Officer?
- Planned and Routine inspection used for discussion in HSE Committee Meeting?

N.3.5   Quarterly Inspection by Safety Consultant

- Is it conducted?
- Is he Qualified and Competent?
- Are contents and coverage adequate?
- Is report reviewed by Top Management?
- Are Corrective Actions taken by contractor?

☐ N.4   PERMIT TO WORK AND EMERGENCY PREPAREDNESS

N.4.1   Method Statements

- Are method statements produced?
- Do they contain clear instructions?
- Are they given to work supervisors?
- Is correct information given to workers?
- Is there step by step description of risk?

N.4.2   Permit to Work in Use

- Is there a procedure for permit to work?
- Issued by authorised person?
- Issued for defined period?
- Workers instructed?
- Are records kept to permits issues?

N.4.3   Emergency Preparedness Plan

- Is there description within safety plan?
- Is it upto date?
- Is it well published?
- Does Project Manager has copy?
- Exercised within the past three months?

N.4.4   Emergency Control Centre

- Available for first-aid box;
- Public addressing system;
- Emergency phone numbers;
- Emergency alarm; and
- Employees name list.

N.4.5   Communication System

- Public Addressing system;
- Emergency power supply;
- Mobile phone in Emergency Care Centre;
- Warming Boards; and
- Records maintained for usage and maintenance of communication system.

N.4.6   Safety Database Requirements

- Link to Police;
- Link to Fire Services;
- Link to Ambulance and Hospital;
- Communication to employees; and
- Displayed on Notice Boards.

N.4.7   First Aid

- Is First Aid included in Safety Plan?
- Is adequate number of first aiders appointed?
- Record keep of qualification;
- First aid boxes supplied; and

- Are first aid boxes equipped.

❑ N.5 REPORTING OF ACCIDENTS AND DANGEROUS OCCURRENCES AND ACCIDENT INVESTIGATION

N.5.1 Reporting to Employer

- Verbal information;
- Written information within 24 hours;
- Delay in reporting;
- Are all accidents identified and recorded?
- Are AFR rates calculated?

N.5.2 Reporting to Govt. Organisation

- Reporting to the Regional Labour Commissioner;
- Reporting to the Welfare Board;
- Reporting to the Director General;
- Reporting to the Police station; and
- Reporting to the District Magistrate.

N.5.3 Incident Reporting

- Is there a proper reporting procedure?
- Is the procedure communicated to all?
- Are reports available for inspection?
- Do reports accurately described incident?
- Is standardised form used?

N.5.4 Follow Up Action

- Does Senior Manager review all reports?
- Is result of investigation published?
- Are workers advised of remedial action?
- Is failure in Management recognised?
- Whether statistics report prepared?

N.5.5 Procedure for Investigation

- Made photographs and sketches;
- Examine involved equipment;
- Interview the eye-witnesses;
- Consulted expert opinion; and
- Environmental conditions.

N.5.6 Incidents Investigation

- Are witness statement taken?
- Is the chain of events identified?
- Is specific sub-contractor identified?
- Is the investigation kit available?
- Is the investigation report made available to the employer?

❑ N.6 HOUSE KEEPING

N.6.1 Organisation

- Adequacy of personnel for Safe, Health and Environment ;
- Housekeeping personnel;
- Training of the housekeeping personnel;
- Employer's approval for housekeeping personnel;
- Intimation of Potential candidate prior approval; and
- Persons provided with suitable logistics/aid.

N.6.2 Access/Egress way

- Free from debris;
- Unprotected opening;
- Free from obstructions;
- Slippery condition; and
- Spillage of water or oil.

N.6.3   Housekeeping at worksite

- Lumbar with protruding nails;
- Unprotected projection;
- Scattered unused materials;
- Fencing and guarding of equipment; and
- Stacking and storing of materials.

N.6.4   Housekeeping at Road

- Tyre cleaning of vehicles;
- Parking of construction vehicles at road;
- Water logging or bentonite spill on road;
- Roads kept clean; and
- Position of barricades lying at roads.

N.6.5   Storage of Cylinders

- Full/Empty separated;
- Gasses separated;
- Protected from whether;
- Contents labeled; and
- MSDS available for each gas.

❑ N.7   WORKING AT HEIGHT

N.7.1   Organisation and Planning

- Adequate number of trained personnel;
- Supervision;
- Planning emergency and rescue;
- Work Permit system; and
- Refresher training.

N.7.2   Scaffolding

- Is scaffolding included in HSE Plan?
- Are scaffolding erected and dismantled by competent workmen?
- Are records kept for inspections?
- Security fixed or buttressed?
- Working platforms free from rubbish?

- Secure ladder access provided?
- Toe board provided?
- Safe for use board erected?
- Availability of base plate?
- Free from rust/corrosion/debris?
- Scaffolds constructed for correct use?
- Are scaffolds constructed of sound material?
- Free from defects?
- Working platforms full boarded; and
- Guardrails and mid rails fitted .

N.7.4   Ladders

- Safety Procedure followed;
- Rubber bush aluminium ladder;
- Landing property;
- Climbing procedure;
- Rungs at proper intervals;
- Are ladders specified in Safety Plan;
- Are records kept of weekly checks?
- Using of bamboo ladders;
- Painting of ladders;
- Sound material;
- Designed as per standard; and
- Maintained property.

N.7.7   Guardrails

- Present at all working platforms;
- Secure attached;
- Sound material;
- Designed as per standard; and
- Maintained property.

N.7.8   Safety Nets

- Approved type;
- Good construction;
- In adequate numbers to be issue;
- Testing; and

- Maintenance

❑ N.8 LIFTING OPERATIONS AND GEARS

N.8.1 Certification

- Procedure is available in HSE Plan;
- Fitness/Test Certificates available;
- Daily inspection records maintained;
- Load chart for lifting appliances; and
- Employer's approval for lifting appliances.

N.8.2 Wire Ropes

- Free from damage;
- Lubricated ;
- Correctly anchored;
- Splicing method; and
- Inspection and Testing.

N.8.3 Slings, Chains and Shackles

- Properly stored when not in use;
- In good condition without defects;
- Market with safe working load;
- Bulldog clips correct fit/number; and
- Correctly used.

N.8.4 Operator and Operator Cabin

- Licence for HMV;
- Competent and skilled;
- Medical fitness certificate;
- Portable fire extinguisher; and
- Defensive driving at IDTR.

N.8.5 Alarms and Signals

- Overload alarm;
- Over hoist alarm;
- Reserve horn;

- Pressure indicators; and
- Outrigger extension alarm.

N.8.6 Safety Indicators

- Free from damage;
- In Operable conditions;
- Overload device tested;
- Overload device operable; and
- Bypass key made available to HSE/IE.

N.8.7 Safety Hooks

- Free from damage;
- Safety latch fitted;
- Safety latch in operable condition;
- Other form of hook closure; and
- Test Certificates.

N.8.8 Outriggers (Mobile Cranes)

- Outriggers locked in position;
- Jacks in good condition;
- Jacks firmly supported;
- Wheels clear/not supporting load; and
- Chassis level.

N.8.9 Rigging requirement

- Rigger qualification and experience;
- Load assessment;
- Type of slings to be used;
- Hocks and lifting assessment; and
- Overhead power line.

N.8.10 Accessories and Controls

- Side and rear view mirror;
- Clutch and brake;
- Swing and Extension control;
- Illumination; and
- Maintenance.

❑ N.9 CONSTRUCTION MACHINERY / HAND TOOLS AND POWER TOOLS

N.9.1 Machinery Fencing

- All moving parts effectively guarded;
- Fencing not removed;
- Is procedure in HSE Plan;
- Warning Board; and
- Emergency stop switch.

N.9.2 Air Receivers

- Fitted with pressure relief valve;
- Annual test carried out;
- All couplers with safety chains/wired;
- Condition of hoses; and
- Noise level under permissible limit.

N.9.3 Grinding Machine

- Appropriate guards fitted;
- Correct size wheel/disc fitted;
- Spindle speed marked on M/s;
- Name plate for equipment specification; and
- Test and Maintenance.

N.9.4 Maintenance and Inspection

- Daily inspection;
- Lubrication;
- Pneumatic and hydraulic pressure;
- Record maintenance; and
- Label displayed in the equipment itself.

N.9.5 Maintenance

- All maintenance properly maintained;
- No maintenance whilst M/c in motion;
- Records of maintenance kept;

- Work permit system; and
- Use of Lock and Tag Out (LOTO).
- N.9.6. Wood working Machine
- Top guard fitted;
- Working space;
- Guards to protect all drive belts;
- Emergency stop switch;
- Push stick used; and

N.9.6 Requirements

- Manufacturer specification;
- Control switch and Devices serviceable;
- Operators Trained;
- All Operators medically fit and above 2;
- Guarding and Maintenance records; and

N.9.7 Personal Protective Equipment (PPE)

- Ear protection;
- Hand Protection;
- Eye Protection;
- Apron; and
- Nose/face mask.

❑ N.10 SITE ELECTRICITY

N.10.1 Power Assessment and Distribution Panel

- Load calculation for power requirement;
- Secure Distribution panel box;
- All cables enter box through glands;
- Noise from diesel generator; and
- Proper earth connection and earth pit and warning signs at appropriate positions.

N.10.2 Cables

- All cables free from damage;
- Cables lying on the ground water;

- Cable joints made by IP 44 connectors;
- Correct storage when not in use; and
- Colour coding.

N.10.3 Electrical professional

- Sufficient numbers;
- Professionally qualified;
- Roles and responsibilities defined;
- Valid license to electrical persons; and
- Training.

N.10.4 Plugs, Sockets and Outlets

- Are all plugs, sockets and outlets IP 44 type?
- Colour coding of plugs and sockets;
- All cables fitted with IP 44 Plugs;
- All equipment connected with plugs; and
- All equipment free from defects.

N.10.5 Work on Site

- Site electricity covered in the HSE plan;
- Name posted on Main Distribution Board;
- Single line and schematic diagram submitted;
- PCEPL's approval for execution; and
- Warning provided.

N.10.6 Earth Pit

- As per standard;
- Wet Condition;
- Pouring 5 litre water per day;
- Earth pipe free from corrosion;
- Earth resistance; and

N.10.7 Voltage/Current

- Check voltage/current limit;
- Rating clearly marked on all equipment;

- Monitored continuously;
- Mismatch of cable and equipment ratings; and
- Properly earthed.

N.10.8 Maintenance

- Regular inspection carried out;
- Records kept;
- Suitable guards/security fenced;
- Faults actioned ; and
- Record maintaining.

❑ N.11 FIRE PREVENTION

N.11.1 Firefighting Personnel

- Adequacy of Firefighting personnel;
- Professionally qualified;
- Employer's approval;
- Intimation of vacancy to Employer; and
- Adequate number of trained person.

N.11.2 Combustible Material

- Used in site;
- Handing of combustible material;
- Stored in separate place;
- Spillage of material; and
- Location of burning site.

N.11.3 Firefighting equipment

- Sufficient quantity of water supply;
- Fire hose and nozzle;
- Fire alarm;
- Condition of fire hydrants; and
- Sufficient quantity available.

N.11.4 Requirements

- Emergency Plan;

- Fire excavation Plan;
- Mock drill;
- Nearest fire brigade phone numbers; and
- Reporting of fire accident to Employer.

N.11.5   Fire Extinguisher

- Adequate numbers;
- Appropriate type;
- Easily accessible;
- Frequency of recharge; and
- Maintenance and inspection.

☐ N.12   WELDING AND CUTTING

N.12.1   Gas Welding/Cutting

- Is procedure in Safety Plan?
- Are cylinders in the cylinder-trolley?
- Are pressure gauges fitted and working?
- Are flashback arresters fitted?
- Are non-return valves fitted?

N.12.2   Condition of Cylinders

- No damage by misuse;
- No rust/corrosion;
- Protected from weather;
- Colour coding proper; and
- Material Safety Data Sheet (MSDS) available.

N.12.3   Electric Welding

- Are welding machines in good order?
- Welding leads free from defect;
- Welding return free from defect;
- Electrode holder properly insulated; and
- Dipping electrode in water when it is hot?

N.12.4   PPE for Welder, Cutter and Helper

- Face and eye protection;
- Gauntlets;
- Safety footwear;
- Nose mask; and
- Ear muff/plug.

N.12.5   Storage of Cylinder

- Is procedure in the Safety Plan?
- Storage in the upright position?
- Full/empty segregated?
- Differed gases separated?
- Are contents labeled?

N.12.6   Hose

- Colour coding;
- Hose clip and clamp;
- Is it free from leak and damage;
- Hose lying on the ground; and
- Joints if any.

N.12.7   Transformer

- Presence of voltmeter and ammeter;
- Separate main power switch;
- Ground Connection;
- Specification plate or board; and
- Protected from weather.

N.12.8   Work Area

- Area clear of flammable substances;
- Smoking inside the work area;
- Fire extinguishers fitted;
- Welding screens available; and
- Ventilation and fume extraction.

Contractor's Cost Control System

Project Cost Control aims at monitoring the cost status of the project and manging changes to the cost baseline and taking remedial actions from changes to the cost baseline as applicable. Cost control processes focus on monitoring the status of the project cost, analysing the cost variance from the baseline, determining the causes of cost change, generating information for making decisions and communicating decisions to the appropriate organisational units for action. This processed information is also used to minimise waste, update current cost baseline and budget estimates, forecast cost trends, and documenting changes. Some organisations also assign the process of limited funding and its management to cost controllers but this is not considered in this chapter as it is a finance function.

In construction projects, generally, there are two parties whose investments are involved i.e. the clients and the contractors. The cost control objectives of the involved parties differ. It is the contractor who executes contracted work and it is he who bears the cost of input resources employed by him for the execution of the work. These input resources and site expenses include the cost of manpower, materials, machinery and capital. He also incurs expenditure on interest on loans, statutory payments, insurance, and so on. In addition, like the client, he has also to control his finances to meet the cash requirements from time to time. His motto is to maximise profit margin by effective cost control.

Considering the above modes of cost control, it is evident that the contractor needs special emphasis on controlling production costs and earned value (performance). And the cost control methodology covered in this chapter has been developed keeping the contractors' needs in view. In a contracted project, the earned value control system enables project costs performance control jointly by the Client and the Contractor and it enablesthem to foresee the trends in their respective budgeted cost at completion.

This chapter describes the methodology for performing the cost control function by the contractor's project monitoring team including cost accountant, headed by the chief planner. This chapter is divided into the following sections:

1. Cost Control Approach
2. Contractor's Direct Cost Control
3. Contractor's Contribution and Indirect Cost Control
4. Contractor's Traditional Budgeted Cost Control
5. Earned Value Management System
6. Earned Value Management System: Past, Present and Future

Cost control principles described in this chapter are applicable to any project, except that the level of details and the tools chosen vary from project to project. Resources productivity control and project cost control are inseparable, therefore, this chapter can be considered as a continuation of the previous chapter. It may be noted that cost control can be effective if the management:

- Implements efficient cost control procedures and systems;
- Develops and updates the cost baseline and control estimates;
- Analyses cost trends to discover potential cost problems and takes remedial measure to control cost;
- Encourages cost conscience and time conscience attitude; and
- Continuously examines methods of execution with the object of total project cost reductions.

❑ 15.1   COST CONTROL APPROACH

15.1.1   Cost Control Related Terminology

There is a fundamental difference in the use of the terms planned value, planned cost of production, standard cost, earned value and production cost of work performed with respect to a work package:

a. *Planned value*. It is the cumulative time-phased planned value of authorised work at contract rate. It represents time-phased cost projections of planned value in the budget.
b. *Planned costs*. It reflect the costs of production planned under normal prevailing conditions.
c. *Standard Cost*. It stands for the production costs achievable under efficient operating conditions.
d. *Earned Value (EV) of work performed*. It implies the monetary value of work completed. In contracted projects, it is equal to the value of work performed at contract rates. Earned value analysis is the method for measuring and analysing project performance at contract rate.
e. *Production cost of work performed*. It is the total expenditure (direct and indirect) incurred in execution of work.
f. *Budget at Completion (BAC)*. In contracted projects, unless revised for extra work or other reasons, it is equal to the total value of work performed at agreed contract rates. It may be noted that the client project baseline is the time phased BAC.
g. *Estimate at Completion (EAC) Forecast*. As the project progresses, the project team may develop a forecast for the estimate at completion (EAC) that may difer from the budget at completion (BAC) based on the project performance.

$$EAC = AC + (BAC - EV)$$

15.1.2 Contractor's Cost Control Approach

Contractor's Cost control focuses on the causes for planned cost changes and how to mitigate, allow or prevent adverse cost change from happening. A project cost control system for effective implementation, as far as feasible, should be easy to understand and simple to implement without creating any interdepartmental and interpersonal conflicts. The system should have least response time, thus enabling quick monitoring and prompt divisions based on simple cost reports initiated at regular frequency by cost incurring centres and a monthly cost and earned value control report compiled by the cost accountant contract manager. The unpredictable changes control is covered under risk management.

Numerous types of cost control systems for construction projects are available in the libraries of management scientists and computer software dealers. Some of these systems are based on traditional historic profit and loss accounting method, standard costing method and the Earned Value method. But there is no tailor-made system, which can suit projects of all types and sizes. Considering that, maximisation of profits (through professional and ethical means) is generally the main motto of the contractors, the contractors cost control system can be designed to control each stage of accounting process that contribute to profit. These stages are shown below:

Nature of Contractor's Cost Control

	Accounting Processes	Control Methodology
A.	Value of Work Performed	Earned Value Control
B.	Direct Cost	Direct Cost Control
C.	Indirect Costs	Indirect Costs Control
D.	Contribution (A- Fixed Overheads)	Contribution Control
E.	Work Package Production Cost	Standard Cost Control
F.	Profit/Loss (A–B–C)	Budgetary Control

Responsibility Centres have vital role to play in controlling project costs. The work-package level responsibility for cost control rests with the Construction Responsibility Centres. In practice, the Direct Cost Control methodology can be used by the contractor for controlling work-package planned production costs at construction centre level to minimise wastage. Contribution control can be viewed with regard to what responsibility centres can contribute towards overall profit and fixed costs. The project management reserve including profitability, contingencies etc. as a whole can best be monitored through the traditional Budgetary Controls at project level. Customized earned

value approach of a contractor can generate cost and schedule related variance for managing performance and forecasting cost and revenue. And all the control methods make use of the concept of Variance Analysis to reason out the cause of variance for making decisions for remedial actions.

Therefore, a construction contractor cost control system can focus on the following:

- Direct Cost Control;
- Contribution Control;
- Budgeted Cost Control; and
- Performance Control using Earned Value Management System.

15.1.3   Cost Baseline Forecasts

For cost control, it is necessary to have time-related baseline forecasts for establishing overall work performed value and production costs. The project work performed value and cost baselines include the time-phased forecast of earned value, planned production cost and cash-flow. These baselines estimates are prepared during project planning stage.

Value and Cost breakdown generally follows the hierarchy pattern of work-breakdown structure. The cost breakdown levels can be divided as under, it enables summing up to the desired level:

Level	Planned Production Costs	Budgeted Earned Value
0	Total project cost	Total project value (BAC)
1	Sub-project cost	Sub-project earned value
2	Task/logistics	Task earned value
3	Work-package costs	Work-package earned value
4	Activity costs	Activity earned value

The costs, at work package level, may be further broken down into the following cost elements where feasible:

- Direct manpower costs;
- Direct material at-site delivered costs;
- Direct equipment, plant and services costs;
- Sub-contract costs;
- Indirect on-site variable and fixed costs; and
- Management margin to cater for profit/loss, contingencies and other expenses.

The planned production cost and earned value should have the standard established for each work package. The actuals get determined as the work progresses. These standards should be updated at the time of revision of the baseline estimates.

The approved original baselines estimate are revised at a predetermined frequency (say half yearly), and the approved revisions are called current baseline estimate.

15.1.4   Measurement of In-Progress Activity

The method of measurement of in-progress work performed percentage varies with the nature of work. Some use 50–50 rule, where 50% progress is taken when the work starts and remaining 50% when it is completed; another rule is 0%–100%, where 90% or 100% progress is considered when the work is completed; and the practice in contracted work is to measure pro-rata quantity of work completed at contract rate. In construction, the various methods of measuring progress of the different types of works can be categorised as under:

1.   *Workdone quantity basis:* In most of the construction tasks or work package or activity, the performance of work is measured as proportionate to the quantity workdone like excavated quantity in earthwork, concrete placed in mass concreting of a dam, actual cost of work performed, and cost of resources employed in formwork. In all such cases, the percentage progress can be calculated as under:

$$\text{Percentage progress (\%)} = \frac{\text{Progress accomplished in units of predominant parameter}}{\text{Total estimate at completion}} \times 100$$

For example, if 25 m³ of earth excavated out of a total of 200 m³, then excavation progress can be determined as under:

$$= \frac{25}{200} \times 100 = 12.5\%$$

2.   *Repetitive-type work packages:* In repetitive activities (or work package) say in a building project, each activity becomes the unit of measure.

$$\text{Percentage progress} = \frac{\text{Units completed} \times 100}{\text{Total number of units}}$$

3.   *Non-repetitive complex construction work packages:* Generally, work packages can be grouped into broad sequential stages or sub-tasks. Thereafter, each stage can be assigned a predetermined percentage of cost. The overall progress at a given point of time can then be estimated by totaling the percentage of stages completed.

4.   *Start/Finish method:* In certain tasks such as preparation of drawings, procurement of materials, planning of project, investigation of soil, the start and completion are well defined, but the progress of intermediate stages is difficult to estimate. For such tasks, an arbitrary percentage can be assigned to mark the start, and the balance can be considered after the task is completed.

15.1.5   Measurement of Earned Value Performance

In contracted projects, project progress on a reported date (data date) is expressed in percentage of budgeted contracted value at completion (BAC). For example, the cost performance of a project can be determined as:

$$= \frac{\text{Cumulative Earned value of Work performed}}{\text{Contract value of project at completion}} \times 100$$

The percentage progress of completed works or a given date data date; can be calculated by tabulating and updating the work progress data, work-package or activity wise, as shown in **Table 15.1**.

Table 15.1

Evaluation of Financial Progress of Work performed on Data Date

Work Package Particulars	Work Package ($)		Progress%	
	Planned Value	**Earned Value**	**Work Package Progress (%)**	**Project (%)**
WPA	PV	EV	Progress (%)	EV ÷ BAC
Activity. 126	15000	15000	100.00	3.00
Activity. 127	20000	16000	80.00	3.20
Activity. 128	45000	9000	20.00	1.80
Total WPA	**80000**	**40000**	**50.00**	**8.00**
WPB	xxxxx	xxxxx	xxx	x.
WPC	xxxxx	xxxxx	xxx	x.
BAC	500000	xxxxx	xxx	xx

15.1.6   Cost Status Report

Cost reports are generally initiated at the level of responsibility centres (cost centres). Preferably, cost reports should be initiated weekly/monthly and their frequency can be increased in the early stages of the project. The cost reports of construction/production centres should reflect a comparison of standard and actual costs. In case of functional departments, cost comparison should be made between budgeted/actual costs. Monthly cost report on a customized format like **Table 12.1**, are initiated by the contractor and submitted after scrutiny by the client project engineer. to project office.

Contractors' project cost controller monitors the responsibility centre cost reports. He updates the project budgeted costs, changes order, keeps track of variations in control estimates, and forecasts the trends pertaining to the remaining project costs using suitable tables, charts and graphs.

Contractor Project Site office also sends a detailed Monhtly Management Report in a prescribed format to its corporate office.

15.1.7 Contractor's Cost Variation Analysis

Cost control inputs include budgeted cost, earned value of work performed, production costand administrative cost baseline and the corresponding actual. It is the variance between the baseline data and the actual that produces variances. If a variance > 0, it is favourable and if variance < 0, it is unfavourable. Cost control is concerned with understanding why the cost variances, both favourable or unfavourable, have occurred, by making appropriate analysis (covered later in this Chapter) and communicating the cost changes to the appropriate organisational units for future actions. The types of variances generally encountered in cost control are given in **Figure 15.1**.

❏ 15.2 CONTRACTOR'S DIRECT COST CONTROL

15.2.1 Objective and Methodology

Direct cost control aims at improving productivity by minimising wastage of input and developing standards for costingand accounting to achieve 'contribution control' and 'budgetary control'. Direct costconstitute over 60% of the total project cost. Direct cost control (with predetermined labour rates and materials purchase price) can best be exercised at the lowest organisational level of a production centre or work-centre, where cost is actually incurred.

The basic concept behind controlling direct costs is that each work package, for which the standard cost is established, is identifiable and measurable, costable . Direct cost control is exercised by comparing the actual direct costs with the standard direct cost, analysing the reasons for variations, and applying corrective measures to improve performance. A prerequisite for controlling direct costs is that the standards must be expressed in terms of the physical and monetary value of each item of resource needed for accomplishing the work package.

Type of resources	Physical measure	Monetary value example
Direct labour	Man-hours (MH)	Labour employment cost
Direct materials	Unit quantity	Materials usage cost
Direct equipment	Equipment hours (EH)	Equipment utilization cost
Direct other expenses		Other direct costs.

Likewise, the actual direct cost being compared with the standard direct cost must aim at measuring the actual quantity and cost of resources in the same unit as that of the standard.

Figure 15.1

Main Cost Variance Breakdown

Nature of Cost Variances

- Earned Value Variances
- Production Cost Variances
- Administration Cost Variances

Earned Value Variances:
- Work done Quantity Variance
- Work done Price Variance

Administration Cost Variances:
- Variable Overheads Variance
- Fixed Overheads Variance

- Variable Cost Variances
- Fixed Cost Variances

Fixed Cost Variances:
- Prod. Overhead Variances
- Admn. Overhead Variances

Variable Cost Variances:
- Variable Overhead Variances
- Direct Cost Variances

Variable Overhead Variances:
- Indirect Labour Variance
- Indirect materials Variance
- Indirect Other Cost Variances

Direct Cost Variances:
- Labour Cost Variances
- Materials Cost Variances
- Other Direct Expenditure Variances

Labour Cost Variances:
- Productivity Variance
- Rate Variance

Materials Cost Variances:
- Usage Variance
- Price Variance

Other Direct Expenditure Variances:
- Equipment Cost Variance
- Other Direct Cost Variance

The resource employement records, covered in **Chapter 14**, form the basis for accounting resources. This direct resources data can enable evaluation of the actual costs incurred for accomplishing each work package.

The primary purpose of introducing standard direct costs is to generate information by comparing actual performance against standards to analyse variance.

Direct cost variance = Standard direct cost – Actual direct cost
If variance > 0, it is favourable (F)
If variance < 0, it is unfavourable (U)

Direct cost control involves the evaluation and analysis of the following variances:

- Direct cost variance,
- Direct materials cost variance,
- Direct labour cost variances,
- Direct equipment cost variance and
- Other direct expenses variance

Direct cost variance is the difference between the standard direct cost of output desired and actual direct cost incurred to accomplish it.

Further, breakdown of the direct cost variances is shown in **Figure 15.2**.

Figure 15.2

Direct Cost Variance Breakdown
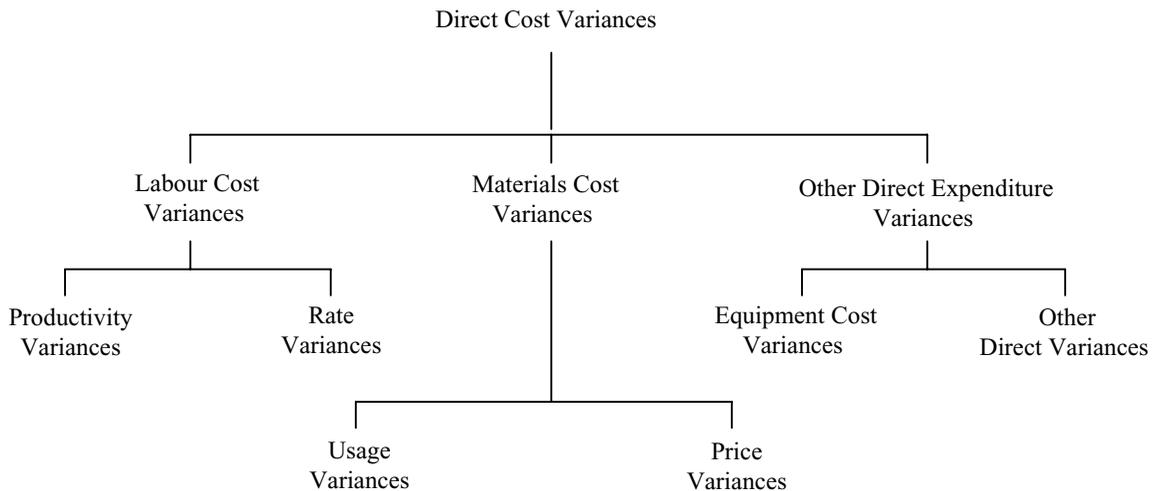
The methodology used for analysing cost variance at the production centre level, is illustrated below with a simple example from the case of a foundation construction task force of a housing unitconstruction project. The concrete placing team has been assigned the task of placing ready-mix concrete in the rafts of the building foundations. Each module of the raft measures 80 m^3 . During a particular week, the placing team concreted four rafts, using 330 m^3 of concrete. It procured ready-mix concrete from the project central batching plant at SR 145 per m^3 delivered at site. It completed placing the concrete in 14 hours, using a concrete pump hired at the rate of SR 120 per hour. The concrete placing team consisting of one foreman, four masons, and eight helpers was employed at the work site for 40 hours to prepare shuttering, rebar steel fixing, concreting, de-shuttering and curing. Average man-hour rate for this team works out as SR 7.90 per man-hour.

At the time of planning standard costs for placing concrete, the concrete price for delivery at the site of work was taken at SR 150 per m^3. The concrete pumping charges were assessed at SR 100

per hour, with pumping rate of about 20 m³ per hour. The concrete wastage at the site during placing was considered as 2%. The concreting team composition was taken as one foreman, six masons and seven helpers with an average rate of SR 8.125 per man-hour with production capacity of laying one raft of 80 cubic metrem five hours. The steel shuttering used for the raft is to be charged at SR 400 per set per raft shuttering.

The standard and actual cost data for concreting four raft foundations is tabulated in **Table 15.2**.

Table 15.2

Cost Data of Concreting Four Rafts

Costs for 4 rafts	Standard Rates for one Raft		Standard Costs for four Rafts		Actual Costs for four Rafts	
	Unit	(SR)*	Qty	(SR)*	Qty.	(SR)*
1. Direct materials costs	M³	150.00	326.4	48 960.00	330	47 850.00
2. Direct labour costs	MH	8.125	448	3640.00	520	4108.00
3. Direct equipment costs	EH	100.00	16	1600.00	14	1680.00
4. Depreciation of shut-tering	Set	400.00	4	1600	4	1600.00
5. Total direct costs				55 800.00		55 238.00

Standard concrete quantity of 4 rafts, each 80 m³ plus 2% wastage = 4 × 80 × 1.02 = 326.4 m³

Note: (SR)* = Saudi Riyal

Summary Cost Data of Concreting Four Rafts

Cost Category	Standard Cost (SR)	Actual Cost (SR)
Direct Materials	48 960	47 850
Direct Labour	3640	4108
Direct Equipment	1600	1680
Shuttering	1600	1600
Total	55 000	55 238

15.2.2 Direct Cost Variance (see Table 15.2)

Take the example of concreting 320 m³ of rafts foundation:

$$\text{Direct cost variance} = \text{Standard direct cost} - \text{Actual direct cost}$$

Now, Standard direct cost = 55 800

Actual direct cost = 55 238

Direct cost variance = 55,800 – 55 238

= (+) 562 (Favourable)

Direct cost control involves the evaluation and analysis of the following variances:

a. Direct cost variance = Standard direct cost – Actual direct cost

    = 55 800 – 55 238

    = (+) 562 (Favourable)

b. Direct materials cost variance = Standard material costs – Actual materials cost

    = 48960 –47850

    = (+) 1110 (Favourable)

c. Direct labour cost variances = Standard labour cost – Actual labour cost

    = 3640 – 4108

    = (–) 468 (Unfavourable)

d. Direct equipment cost variance = (Standard – Actual) equipment cost

    = 1600 – 1680

    = (–) 80 (Unfavourable)

e. Other direct expenses variance = Standard cost – Actual cost

    = 1600 – 1600

    = 0 (No charge)

The above material, labour and equipment variances can be further analysed to determine rate (or price) and productivity variances.

15.2.3   Direct Materials Cost Variance (see Table 15.2 and Figure 15.3)

This is the difference between the standard direct materials cost and the actual materials cost for the same output:

Direct Material Cost Variance = Standard Materials Cost – Actual Materials Cost

    = 48960 – 47850

    = 1110 (Favourable)   (A)

Material cost variance = Standard materials cost – Actual materials cost

    = Materials usage variance + Materials price variance

Materials usage varaiance = Standard rate (Standard quantity – Actual quantity)

Materials price variance = Actual quantity (Standard rate – Actual rate)

The direct materials cost variance is made up of materials usage variance and materials price variance. These variances and their further breakdown can be evaluated using a generalised materials variance analysis model sketched in **Figure 15.3**. This model also shows the relationship among various components of materials cost variances taking the raft concreting example.

Figure 15.3

Direct Materials Cost Variances
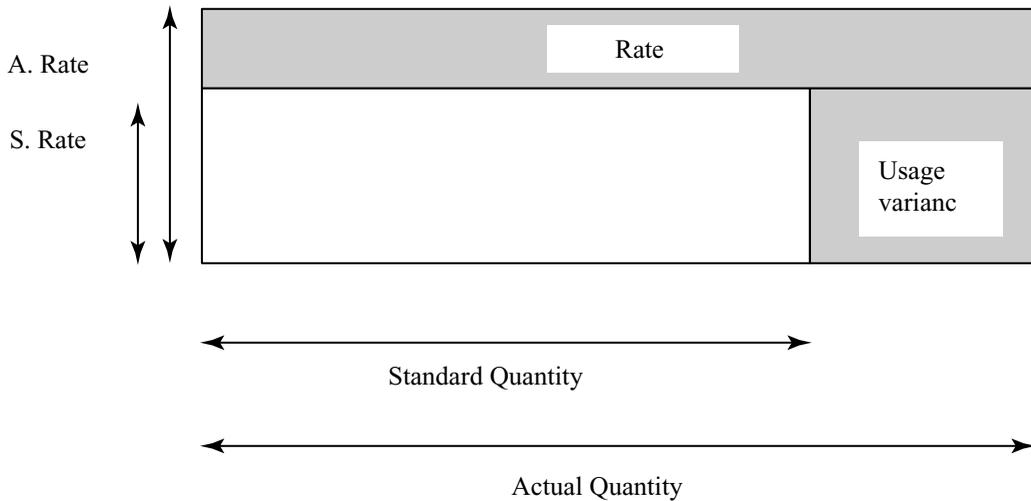
Materials cost variance = Materials usage variance + Materials price variance
Where,

1. Materials usage variance = Standard rate (Standard quantity – Actual quantity)
    = 150 (326.4 – 330) (from **Table 15.2** and **Figure 15.3**)
    = (–) 540 (Unfavourable)   (B)

Unfavourable materials usage variance reveals that the wastage has been greater than the expected standard wastage and it needs to be controlled in future similar works.

Materials price variance = Actual quantity (Standard rate – Actual rate)
= 330(150 – 45) (from **Table 15.2** and **Figure 15.3**)
= 1650 (Favourable)   (C)

Favourable materials price variance shows the savings on account of discounted price *vis-à-vis* prices considered at the time of estimation of standards.

2. Therefore, direct materials cost variance = B + C
    = –540 + 1650
    = 1110 (Favourable)
    (It is same as A above)

3. Materials productivity variance (%) = Standard wastage % – Actual wastage %

$$2\% - \frac{(330 - 320)}{320} \times 100$$

(2%–3.125%) of 4 rafts concrete quantity of 80 m^3 each (i.e. total 320 m^3 concrete)

$$= (-)\ 1.125\%\ \text{(Unfavourable)}$$

$$= \frac{-1.125 \times 320 \times 150}{100}$$

$$= -\text{SR } 540\ \text{(It is same as B above)}$$

Now, in case of materials like concrete manufacturing, the materials usage variance analysis can be further extended to cover mix variance and yield variance:

Materials mix variance = Standard rate × Standard yield (Standard mix – Actual mix)
Materials yield variance = Standard rate × Standard mix (Standard yield – Actual yield)

15.2.4   Direct Labour Cost Variance (see Table 15.2 and Figure 15.4)

This is the difference between the standard labour and the actual labour cost for performing the same output. In the given example (see **Table 15.2**)

1. Labour cost variance = Labour standard cost – Labour actual cost
2. Labour cost variance = Labour operating variance + Labour rate variance
3. Labour operating variance = Standard rate (Standard time – Actual time)
4. Labour rate variance = Actual time (Standard rate – Actual rate)

Direct labour cost variance = Standard labour cost – Actual labour cost
$$= 3640 - 4108$$
$$= (-)\ 468\ \text{(Unfavourable)}$$

The labour cost variance can be further analysed using generalised labour cost variance model shown in **Figure 15.4**. The two components of the labour cost variance are:

Labour operating variance = Standard rate (Standard time – Actual time)
$$= 8.125\ (14 \times 8 \times 4 - 13 \times 40)\ \text{(from \textbf{Table 15.2} and \textbf{Figure 15.4})}$$
$$= 8.125\ (448 - 520)$$
$$= (-)\ 585\ \text{(Unfavourable)}.$$

Labour rate variance = Actual time (Standard rate – Actual rate)
$$= 40 \times 13\ (8.125 - 7.9)$$
$$= 117\ \text{(Favourable)}.$$

Note: The sum of labour operating variance and labour rate variance, calculated above is equal to direct labour cost variance, i.e.

Labour operating variance + Labour rate variance = − 585 + 117
$$= (-)\ 468$$
$$= \text{Direct labour cost variance}.$$

Figure 15.4

Direct Labour Cost Variances
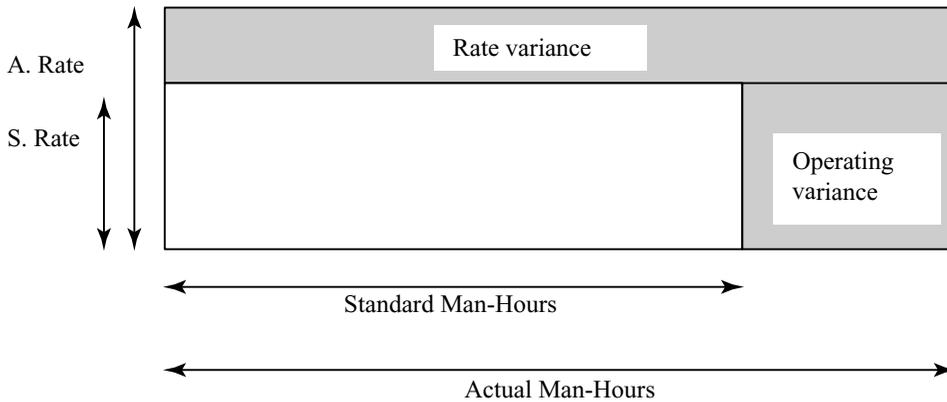
15.2.5   Equipment Variance

This is the difference between the standard equipment cost and actual equipment cost for accomplishing the same output. The Equipment variance analysis model is similar to that of the labour variance analysis. Proceeding similarly:

Equipment cost variance = Standard equipment cost – Actual equipment cost
$$= 400 \times 4 - 1680 \text{ (from \textbf{Table 15.2})}$$
$$= (-) \ 80 \text{ (Unfavourable)}.$$

This equipment cost variance is further split up into:

Equipment operating (or productivity) cost variance
$$= \text{Standard rate (Standard time – Actual time)}$$
$$= 100 \ (4 \times 4 - 14) \text{ (from \textbf{Table 15.2})}$$
$$= 200 \text{ (Favourable)}$$

Equipment rate variance = Actual time (Standard rate – Actual rate)
$$= 14 \ (100 - 120) \text{ (from \textbf{Table 15.2})}$$
$$= (-) \ 280 \text{ (Unfavourable)}.$$

15.2.6   Summary of Direct Cost Variances

All the variances evaluated for concreting 4 rafts can be summarised as follows:

1. Direct cost variance   (+) 562 (Favourable)
2. Direct materials variance
    a. Materials usage variance   (–) 540 (Unfavourable)

	b. Materials price variance	(+) 1650 (Favourable)
3.	Direct labour variance	
	a. Labour operating variance	(–) 585 (Unfavourable)
	b. Labour rate variance	(+) 117 (Favourable)
4.	Direct equipment variance	
	a. Equipment operating variance	(+) 200 (Favourable)
	b. Equipment rate variance	(–) 280 (Unfavourable)
		562 (Favourable)

15.2.7 Causes of Unfavourable Direct Cost Variances

Direct cost control and resource productivity control are inseparable. The object of direct cost control is to minimise cost through cost variance analysis, and this mainly depends upon minimising wastage in the employment of resources.

Cost variance can result from many causes. Some of the main causes for unfavourable variances are given below. This list is indicative and not comprehensive:

a. *Material price variance*. Increased prices, unplanned purchases.
b. *Materials usage variance*. Sub-standard materials, excessive wastage, other reasons resulting in low materials productivity.
c. *Labour rate variance*. Wage increases, labour associated costs increases, unforeseen social severity legislations.
d. *Labour operating variance*. Sub-standard materials used, inappropriate labour skills, lack of work preparation, other reasons resulting in low productivity.
e. *Equipment rate variance*. Higher renting charges, incorrect matching of machine with the job.
f. Equipment operating variance. Rise in fuel prices, excessive repairs, unplanned idle time, other reasons resulting in low productivity.
g. *Other common reasons*. Unrealistic standards, higher resource procurement costs, higher sub-contract costs, mismanagement of resources.

There is a difference between direct cost control and direct cost reduction. Direct cost control prevents wastage within the existing environment. On the other hand, cost reduction is a creative process, which aims at reducing resourceexpenditure using techniques like value analysis, work study, automation, quality improvement, and other innovative approaches.

❑ 15.3 CONTRIBUTION AND INDIRECT COST CONTROL

15.3.1 Indirect Cost Breakdown

Production cost constitutes direct costs and indirect costs. Direct cost control methodology is covered earlier in this chapter. Direct cost items account for the major portion, say 70%, of the production costs. Indirect costs are numerous, accounting for a comparatively lesser percentage (say 30%)

of the production costs. In the current competitive market, it is important that indirect costs should be controlled.

As already mentioned in **Chapter 11**, the indirect cost of each responsibility centre can be broadly divided into two categories, i.e. production-related variable overheads and time related periodic fixed overheads. Theoretically, no production implies nil variable overheads. In reality, fixed overheads are incurred independent of the level of production.

Production-related variable overheads are incurred by almost all the responsibility centres. Construction centres have production overheads on what they produce. Similarly, service centres incur cost on what they serve and this expenditure gets apportioned as service centres' variable overheads on construction centres. Even in the administration centre, there is a component of variable overheads. All the fixed overheads in the project are generally ordered, accounted for and controlled by the administrative responsibility centre. The project indirect cost for accounting and control purposes can be categorised as under:

- Construction centre variable overheads;
- Services centre variable overheads;
- Administration centre variable overheads; and
- Project fixed overheads.

Each of the above heads can be divided into indirect manpower costs, indirect material costs, indirect equipment costs, and other indirect costs, if considered necessary.

The indirect cost control brings out variances, and the reasons for variances between the budgeted and actual, in respect of the variable and fixed overheads. For accounting purposes, if the fixed costs are charged to the profit margin then balance overheads are all variable in nature. This concept is at the root of contribution control methodology.

15.3.2 Contribution Control Methodology

Profitability of the project and performance of cost centres can best be controlled by using the 'contribution control' methodology.

Contribution is defined as the difference between the work performed sales value and the variable cost of these sales. Variable cost of the work performed represent the production-related variable component (including direct cost) of production cost. It excludes the fixed overheads.

$$\text{Contribution} = \text{Work performed value} - \text{Variable costs} \qquad \text{(A)}$$
$$\text{But, profit} = \text{Work performed value} - (\text{Variable costs} + \text{Fixed overheads}) \qquad \text{(B)}$$

From Eqs. (A) and (B) above:

$$\text{Contribution} = \text{Profit} + \text{Fixed overheads}$$

It shows that:

a. If the contribution exceeds fixed overheads, profit is made.

b. If the contribution equals fixed costs, break-even results.
c. If the contribution is less than fixed costs, the projects is running at a loss.

'Contribution' can be viewed as the contribution of the responsibility centres towards the profits and fixed overheads of the project, and it is taken as a measure to judge the cost performance of the centre. For example, if at the end of the month, a construction responsibility centre executes works worth $1 000 000 (payable), and corresponding expenditure on its direct costs and variable overheads is $900 000, then

$$\text{Its contribution to the project} = \text{Work performed value} - \text{Variable costs}$$
$$= \$1\ 000\ 000 - \$900\ 000$$
$$= \$100\ 000.$$

Contribution is evaluated generally in terms of work packages sold, or for sold work units as listed in bill of quantities. It is preferable to have the work package as the data base for computing contribution as each work package has a specified scope of work with a fixed sale price. It has its predetermined production cost objectives, expressed as standard variable cost, consisting of direct cost and variable overheads and standard rate of absorption for fixed overheads.

Standard Sales	-	Standard Variable Costs	=	Standard Contribution
I		I		I
Actual Sales	-	Actual Variable Costs	=	Actual Contribution
II		II		II
Sales Variances	-	Variable Cost Variances	=	Contribution Variances

Notes:

The concept of variability of cost varies with the level of project hierarchy:

a. At the corporate level, barring a few exceptions like depreciation on equipment and the management costs, all the project costs, which can be identified with the execution of the project, can be considered as variable.
b. At the project level all the overhead costs being incurred by a responsibility centre, except management cost of a responsibility centre can be considered as variable.
c. Similarly, at the responsibility level, all production related costs can be considered as variable; and those which are periodic in nature, like supervisor's salary, can be treated as fixed costs, to be accounted for by the project management.

Contribution control makes use of variance analysis technique to trace the causes of work performed value variance and variable cost variance.

❑ 15.4 TRADITIONAL BUDGETED COSTS CONTROL

15.4.1 Object

Budgetary control is the process by which the managers of responsibility centres exercise control over budgeted costs through continuous appraisals of actual costs and revenue with the budgeted costs and revenue receipts. The budgetary control process lays emphasis on the identification of areas of responsibility of individual managers and regular comparisons of their actual achievements with budgeted targets.

15.4.2 Accounting Budgeted Costs

The first step in the budgetary control process is to establish a system for accounting revenue and costs generally conforming to the pattern adopted while developing the budget. This calls for a suitably designed integrated finance and cost accounting system. Broadly, these accounting areas can be divided into the following heads of accounts:

a. Sales revenue accounting:

- Original works progress
- Materials-at-site inventory
- Works change orders

b. Production costs accounting:

- Materials costs
- Manpower costs
- Equipment costs
- Other production costs

c. General and administration costs:

- General financial adjustment accounts Non-operating incomes like interests on deposits, short-term investments, discounts, etc.
- Non-operating expenses such as taxes and dividends paid.

General financial adjustment accounts are maintained to carry out financial adjustments in profit and loss accounts, and these are not considered for cost control purpose. Contribution and flexible budget concepts are tools used for exercising costs and profits control.

15.4.3   Cash Flow Control

Cash-inflow or revenue at the project site, is made up of the value of work performed at pre-determined prices (earned value), the cost of site materials inventory to be paid at an agreed percentage of purchase cost and value of work changes (over contracted quantities).

Revenue control aims at the analysis of variances for the work executed. These varances can be computed as under:

The budgeted revenue variance can be accounted by:

- Measuring quantities of work performed and its value at the contract price generally given in the bill of quantities;
- Stock taking of direct materials and other payable items at the site;
- Evaluating change orders (deviations from the original contract);
- Estimating and billing all payable items at the site; and
- Comparing the revenue actually approved and the revenue planned as per budget and analysing the causes for variations.

15.4.4   Accounting Work Progress

Earned value of work performed at predetermined standard price or contract rate, stated in the bill of quantities is assessed by measuring the quantity of work performed, recording the details of these measurements in measurement books and then evaluating the value of work performed for each item of work:

$$\text{Value of work performed} = \text{Contract rate} \times \text{Actual quantity of work performed}$$

The value of the work progress is then compiled, item-wise, in the prescribed manner. The format used for consolidating values of work progress varies from project to project, and depends on the financial and accounting methodology devised by the client. A typical format is shown in **Table 12.1**. It may be noted that the value of work performed during the month is calculated by evaluating the cumulative work performed at the end of the month and then subtracting the cumulative value of work performed approved in the previous month.

15.4.5   Accounting Direct Materials Inventory

The valuation of direct materials-at-site inventory involves stock taking of materials lying at site and then multiplying these with their unit price, generally as shown in the materials purchase invoices. The admissible advance for the value of materials-at-site is then computed by multiplying the total purchase value of these materials with mutually agreed percentage, as incorporated in the terms of the contract. It may be noted that the value (and quantity) of materials at-site consumed during the month can be determined as under:

		Original Work	Material at Site	Work Change Order
(A)	Budget forecast cumulative	XXX	XXX	XX
(B)	Contract value of work done			
	(a) Upto previous month	XXX	XX	XX
	(b) During current month	XX	X	X
	(c) Cumulative (B)	XXXX	XXX	XX
(C)	Actual approaved (cumulative)	XXX	XX	XX
(D)	Work done value Variance (A–B)	XX	XX	X
(E)	Price Variance (B–C)	XX	X	X
(F)	Budget Variance (A–C)	XXX	XX	XX

Value of materials-at-site consumed during the month

= Value of opening stock of the month
+ Value of materials inducted during the month
– Value of closing stock at the end of the month.

15.4.6 Accounting Work Changes Order

In construction projects, work changes through deviations in orders are inevitable. In some projects such deviations may run into hundreds. The cost of extra works can be determined by any of the following mutually or contractually agreed methods:

- Pro-rata assessment based on elemental unit rates given in the bill of quantities;
- Lump sum price for each work change order;
- Actual cost plus fixed percentage to cater for contractor's overheads and profits; and
- Actual cost or guaranteed maximum price, whichever is greater.

For accounting purposes, each change order for extra work is allotted a serial number; it is documented and resources employed for its execution are properly accounted. The revenue accrued from a deviation order is not added to the revenue from sales of items of the original work progress and each is treated separately.

15.4.7 Revenue Variance

Budget revenue variance encountered in construction projects is made up of (a) sale price variances and (b) work performed quantity variances. These are explained below:

a. Work performed quantity variance determines the changes in quantity of work performed from budgeted quantity of work. It is a general practice to analyse the original work progress, materials at the site, and work changes separately.

b. Earned Value sale price variance shows the changes between the standard sale price and the actual selling price. In contracted projects, unless the work completed is defective, the sale price is fixed and it is reflected in the bill of quantities. Accordingly, in original contracted works the sale price variance can only arise as a result of deductions made from the standard price due to defective or incomplete work.

❑ 15.5   PERFORMANCE CONTROL USING EARNED VALUE MANAGEMENT

15.5.1   Why Use Earned Value Management System?

Earned Value Management (EVM) is a valuable tool for planning, monitoring and controlling project cost and time performance. EVM establishes a work package earned value baseline by integrating project scope, time schedule and cost objectives. This work package control account is used for performance evaluation on a given date.
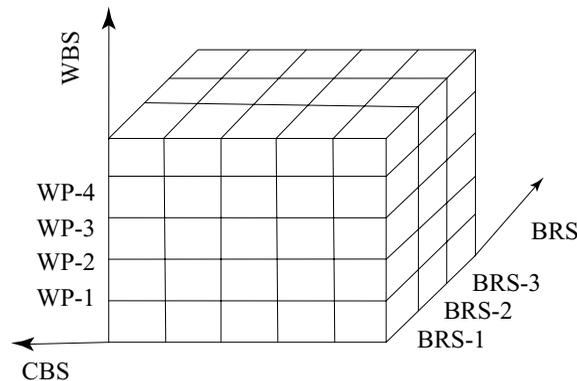
Control Account Database Structure

Earned Value Management (EVM) is the process of measuring cost performance of project work against a baseline plan. Analysis of variance from the baseline using Earned Value Management System yields variety of data that are analysed to determine the current status, initiate corrective actions and forecast future trends. Its mathematical formulae are useful to compare budgeted cost work performed against work planned and actual cost of the work performed. The application of EVM enables better integration of cost and time schedule control with responsibility defined in OBS. It provides better overall picture of performance and gives better forecast of the final costs at completion.

EVM considers project schedule status and updated costs incurred at periodic intervals and provide an integrated approach for measurement of cost and schedule performance during the course of project implementation. The performance is characterised by the variances between the planned

performance and actual performance. The technique also forecasts the future cost trends based on current performance for taking corrective measures in the event of unfavourable and favourable cost and time performance.

15.5.2   Earned Value Performance Parameters

In EVM System, the three parameters that influence the project performance control are:

1. **Planned Value (PV)**: It is the cumulative planned value of authorised work scheduled for completion on date at contract rate. Cumulative planned value curve plotted at various periodic interval is called the project cost baseline. It represents time-phased cost projections of planned value in the budget for example, if a project has a budget of Rs1000,000, and five month schedule shows completion of 40 percent of the value of project work, the PV for the fifth month is Rs 400,000. The Planned Value is also called the Budget Cost of Work Schedule (BCWS).

2. **Earned Value (EV)**: It is the cumulative value of the authorised work actually executed on a given date at contract rate. It is obtained by multiplying the cumulative values of the quantum of the work actually executed with the corresponding budgeted unit costs of the respective activities. For example, if a project has a budget of Rs. 1000 000 and the work completed to date represents 25 percent of the entire project work, its EV is Rs. 250 000. This cumulative earned value curve is also called 'budgeted cost of work performed' (**BCWP**).

3. **Actual Cost (AC)**: It is the cumulative actual costs including apportioned management reserve incurred in the project on data date. The actual cumulative cost curve is developed progressively with the completion of activities during the course of project implementation. During execution, the actual cost variance with respect to the planned cost, creates favourable or unfavourable project situations. For example, if a project has a budget of Rs. 1000 000 and Rs. 400 000 has been spent on the project to date, the AC of the workdone would be Rs. 400 000. Actual Cost is also known as Actual Cost of Work Performed (ACWP).

The above three parameters PV, EV and AC can be monitored in cumulative values and reported at regular frequency say on monthely basis to know if the project is progressing favourably or unfavourably as can be seen in F**igure 15.5**.

15.5.3   Earned Value Variances, Performances and Trends Measures

The three basic parameters (PV, EV and AV) of Earned Value System are used to measure variances, performance efficiency and forecast trends as are shown below:

Variance Measures   If the project progresses exactly as per cost and time integrated plan, the three parameters will be identical. But this is a rare case. PV, EV and AC parameters, when plotted graphically against the time scale, resembles the 'S' curve pattern, see **Figure 15.5**.

Figure 15.5

Cost and Schedule Variances
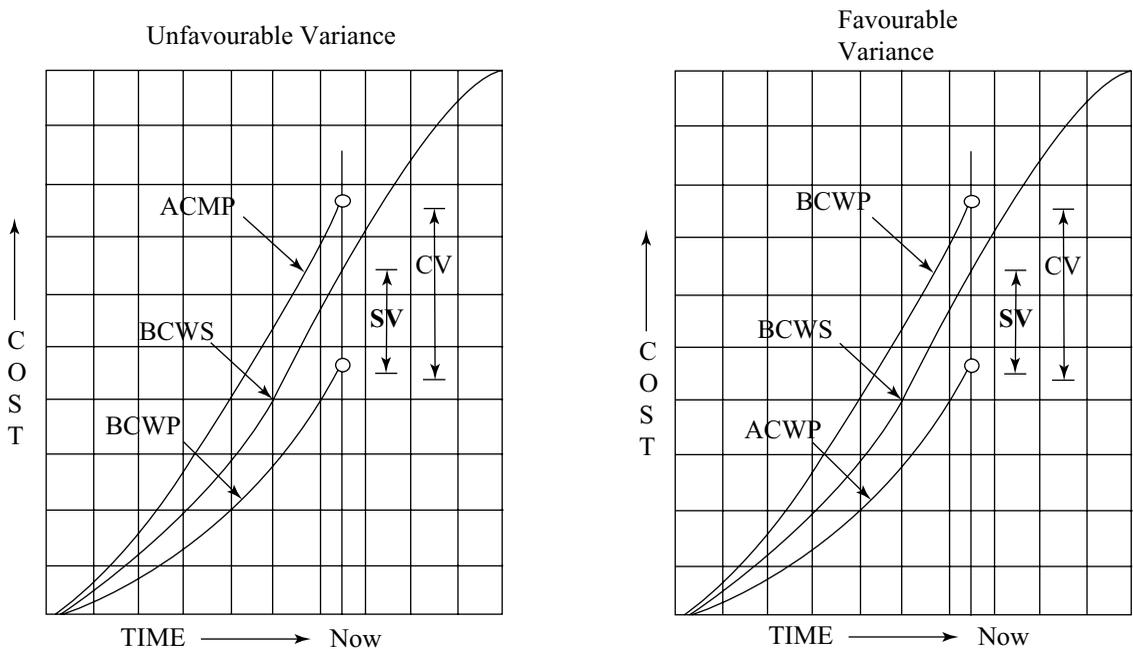
The difference between EV-AC and EV-PV during implementation phase, generates variances. To quote example, graphical representation of the PV function along with two typical cases of EV and AC, one with favourable and the other with unfavourable variances is given in **Figure 15.5**.

In both cases on reported date (Time Now), there is variance in between EV and AC; and, between EV and PV. These variances are defined as under:

Cost variance.   Cost variance is computed by comparing actual performance (AC) with the budgeted cost of work performed (EV). Mathematically it is computed as under:

$$\text{Cost variance} = \text{EV} - \text{AC}$$

a. If the cost variance is positive, then the project has a cost under-run, i.e. the cost incurred is less than the planned or budgeted cost.
b. If the cost variance is negative, then there is a cost over-run, i.e. the cost incurred is more than the planned or budgeted cost.
c. If the cost variance is zero, then the project is proceeding according to the budgeted cost.

Schedule variance.   Schedule variance is computed by comparing planned performance with the Mathematically it is computed as under:

Earned Value Management System Performance Measures			
Parameters	**Variance Measure**	**Efficiency Measure**	**Cost Trends Forecasts**
Planned Value (PV)	Cost Variance CV = EV – AC	Cost Performance Index CPI = EV/AC	Budget at Completion = BAC
Earned Value (EV)	Schedule Variance SV = EV – PV	Schedule Performance Index = SPI = EV/PV	Estimate to Completion = ETC = EAC – AC
Actual Value (AV)	Variance at Completion = VAC = BAC – EAC	To-Complete Performance Index = TCPI = (BAC – EV)/(BAC – AC), or = (BAC – EV)/(EAC –AC))	Estimated at Completion = EAC = BAC/CPI, or, = AC + BAC – EV, or = AC + ETC or = AC +(BAC – EV)/ (CPI × SPI)
		(See **Section 15. 5.3.2**)	(See **Section 15.5.3.3**)

$$\text{Schedule variance} = EV - PV$$

a. If schedule variance is positive, then the project is ahead of its planned cost, i.e. earned value of the work performed is higher than the planned or scheduled earned value.
b. If scheduled variance is negative, then the project is behind its planned cost, i.e. earned value of work performed is less than the planned or scheduled earned value.
c. If scheduled variance is zero, then the project is proceeding according to the planned schedule.

Variance at Completion.   On a data date:

$$VAC = BAC - EAC;$$

Where,

BAC = Budget at Completion
EAC = Estimate at completion (It is explained in the next section).

Note: CV and SV are the commonly analysed measurements.

Earned Value Performance Efficiency Measures   Performance measures. Variance analysis reveals the extent and causes of variance. On the other hand, performance indices determine how efficiently the task was done and what its implications will be on the future trends Earned value management is a system used to measure project performance efficiency. The performance efficiency is analysed by evaluating efficiency indices as under:

• Cost performance index = EV/AC. It indicates cost efficiency.

- Schedule performance index = EV/PV. It shows schedule efficiency.
- To-Complete Performance Index. It indicates the cost efficiency that is required to achieve the balance goals subject to various options.

Procedure for analysis of the variances and trends involves the following steps:

Cost performance index.   CPI measures the value of work completed compared to the actual cost incurred on the project. It shows the cost efficiency of the work completed. Cost variance indices indicate the cost overrun/under-run.

$$\text{Cost variance} = EV - AC$$

Cost variance as a percentage of the earned value:

$$CV(\%) = \frac{EV - AC}{EV} \times 100$$

$$\text{Cost performance index} = CPI$$
$$= EV/AC$$

CPI less or more than one indicates cost over-run and cost under-run respectively.

Schedule performance index.   SPI determine deviations from the schedule. The time over-run/under-run reveal the cost and time the project is behind or ahead of schedule.

$$\text{Schedule variance} = EV - PV$$
$$\text{Schedule performance index} = EV/PV$$

Schedule variance as a percentage of the schedule achievement (SV%):

$$SV(\%) \frac{EV - PV}{EV} \times 100$$

Notes:

1. An index of 1.0 or greater indicates a favourable performance and less than 1.0 implies an unfavourable trend.
2. The cost performance Index and schedule performance index are also expressed as percentage to indicate the percentage efficiencies of cost and schedule performance.
3. CV and SV are commonly analysed measurements.

To-Complete Performance Index.   TCPI is a measure of the cost of performance with the remaining resources that is required to achieve the goals.

$$TCPI = (BAC - EV)/(BAC - AC) \dots$$

If the originally planned efficiency is maintained to achieve the completion as per plan.

When it becomes obivious that BAC is no longer viable; the EAC may replace BAC in the TCPI calculation. The equation of TCPI based on EAC for the remaining works is given by:

$$TCPI = (BAC - EV)/(EAC - AC) \ldots$$

If the current efficiency is maintained to achieve the completion at the current EAC.

Percentage Project Progress

$$\text{Completed on data date} = \frac{EV}{BAC} \times 100$$

$$\text{Spent on data date} = \frac{AC}{BAC} \times 100$$

$$\text{Scheduled to be achieved on data date} = \frac{PV}{BAC} \times 100$$

Where, BAC is the budgeted cost at completion.

15.5.4 Trends Forecasting Parameters

There are three basic forecasting parameters in the EVM relating to completion costs. These are budget at completion (BAC), estimate to complete (ETC) and estimate at completion (EAC).

Budget at completion (BAC).   It is the total cumulative planned budgeted cost of all the project activities to be performed to be performed as per the planned schedule. It is the total base line cost and end value of the planned value curve.

Estimate to complete (ETC).   It is the cost estimate to complete the balance work as on data date and shall be based on realistic new estimate worked out for the completion of the balance work including the allowances for the risks. ETC to complete the balance work can be assessed on the basis of CPI achieved up to the data date as under:

$$ETC = \frac{(BAC - EV)}{CPI}$$

Estimate at Completion (EAC).   It is a new revised expected total cost estimate at completion of all works. It depends upon various courses of action after the review is made on the data date. EAC is determined based on one of the following considerations:

a.   If the current cost performance index (CPI) will continue till project completion, then EAC is equal to ETC.

$$EAC = ETC = \frac{BAC}{CPI}$$

Note here EAC is a new revised cost estimate at completion.

b. If EAC is calculated as the sum of the actual cost incurred as on data date and the balance work controlled and completed at the original budgeted rates.

$$EAC = AC + (BAC - EV)$$

c. If EAC is calculated as the sum of the actual cost incurred as on report date plus the cost to complete the balance work on realistic revised estimates (ETC)

$$EAC = AC + ETC$$

d. If EAC forecast for ETC work considering both CPI and SPI factors, then

$$EAC = AC + (BAC - EV)/(CPI \times SPI)$$

15.5.5   Example: ABC Project Earned Value Analysis

Consider the data reported below at the end of 10th week of ABC project, which is schedule of completion at the end of 20th week; BAC is the budgeted cost at completion (see **Table 15.3**).

Cost variance.   Cost variance is computed by comparing actual performance (AC) with the budgeted cost of work performed (EV).

ABC Project

Cost Variance (CV) = EV – AC = 80.4 – 90.0 = (–) 9.6 (overrun)
  Cost Variance % = CV/EV = (–) 9.6/80.4 × 100 = –11.9% (of EV)
  Cost Variance % = CV/BAC = (–) 9.6/160 × 100 = –6% (of BAC)

---

a. If the cost variance is positive, then the project has a cost under-run, i.e. the cost incurred is less than the planned or budgeted cost.
b. If the cost variance is negative, then there is a cost overrun, i.e. the cost incurred is more than the planned or budgeted cost.
c. If the cost variance is zero, then the project is proceeding according to the budgeted cost.

Cost overrun and cost under-run are usually expressed in percentage. These can be represented graphically as shown in **Figure 15.6**.

Each point of cost overrun (or under-run) is derived using the following relationship:

ABC Project

$$\% \text{ complete} = (EV/BAC) \times 100$$
$$= (80.4/160) \times 100$$
$$= 50.25\%$$

$$\text{Cost overrun (\%)} = \frac{BCWP - ACWP}{BCWP} \times 100 = \frac{EV - AC}{EV} \times 100$$

$$= (-)\ 11.9\% \text{ (Overrun)}$$

$$\text{Cost overrun (\%)} = \frac{BCWP - ACWP}{BAC} \times 100 = \frac{EV - AC}{BAC} \times 100$$

$$= (-)\ 6\ \% \text{ (Overrun)}$$

Schedule variances.   Schedule variance is computed by comparing budgeted cost of work performed (EV) with the budgeted cost of work scheduled (PV).

ABC Project

$$\text{Schedule variance} = EV - PV = 80.4 - 92.1 = (-)\ 11.7 \text{ (Overrun)}$$

$$\text{Time Schedule overrun (\%)} = \frac{BCWP - BCWS}{BCWS} \times 100 = \frac{EV - PV}{PV} \times 100$$

$$= (-)\ 12.7\% \text{ (overrun)}$$

---

a. If schedule variance is positive, then the project is ahead of its planned cost, i.e. earned value of the work performed is higher than the planned or scheduled earned value.
b. If scheduled variance is negative, then the project is behind its planned cost, i.e. earned value of work performed is less than the planned or scheduled earned value.
c. If scheduled variance is zero, then the project is proceeding according to the planned schedule.

When the project is behind schedule, there is a time overrun. Similarly, there is a time underrun, if the project is ahead of schedule. Time overrun (or under-run) is equal to the period the project is behind or ahead of the schedule.

Table 15.3

ABC Project Earned Value Analysis

Activity	Cost Progress (%)		BAC	PV(PV)	EV (EV)	AC (AC)
	Planned	Earned				
a	b	c	d	b × d	c × d	e
C	100	100	6	6	6	8
H	45	40	34	15.3	13.6	16
B	100	100	4	4	4	5
G	100	100	8	8	8	7
L	56	20	21	11.8	4.2	8
E	100	100	8	8	8	8
J	70	60	16	12	9.6	10
F	—	—	6	—	—	—
K	—	—	12	—	—	—
D	100	100	15	15	15	18
I	100	100	12	12	12	12
A	—	—	18	—	—	—
			160	**92.1**	**80.4**	**90**

Time overruns and time under-run are usually expressed in terms of units of time, say a month. These can be represented graphically as shown in **Figure 15.6**. These graphs provide information about cost and time-budgeted or actualsin one sheet of paper on a common time scale, are useful devices for monitoring and controlling costs.

Cost trends/forecasts.   Variance analysis reveals the extent and causes of variances. On the other hand, performance efficiency determines how efficiently the task was done and what its implications will be on future trends. Future trends in productivity, cost and time performance can be predicted as under:

$$\text{Cost Performance Index} = EV/AC = 80.4/90.4 = 0.89$$
$$\text{Schedule Performance Index} = EV/PV = 80.4/92.1 = 0.87$$

An index of 1.0 or greater indicates a favourable performance and less than 1.0 implies an unfavourable trend.

Performance indices vary during the execution of a project. Minor variations are normal, but significant changes in indices call for forecasting of the probable performance on completion. These forecasts can be prepared by extrapolating the past data to produce the best fit curve, and thereafter extending the same for predicting performance on completion as under:

Figure 15.6

Integrated Time-Cost Performance Chart (Performance be Scheduled)
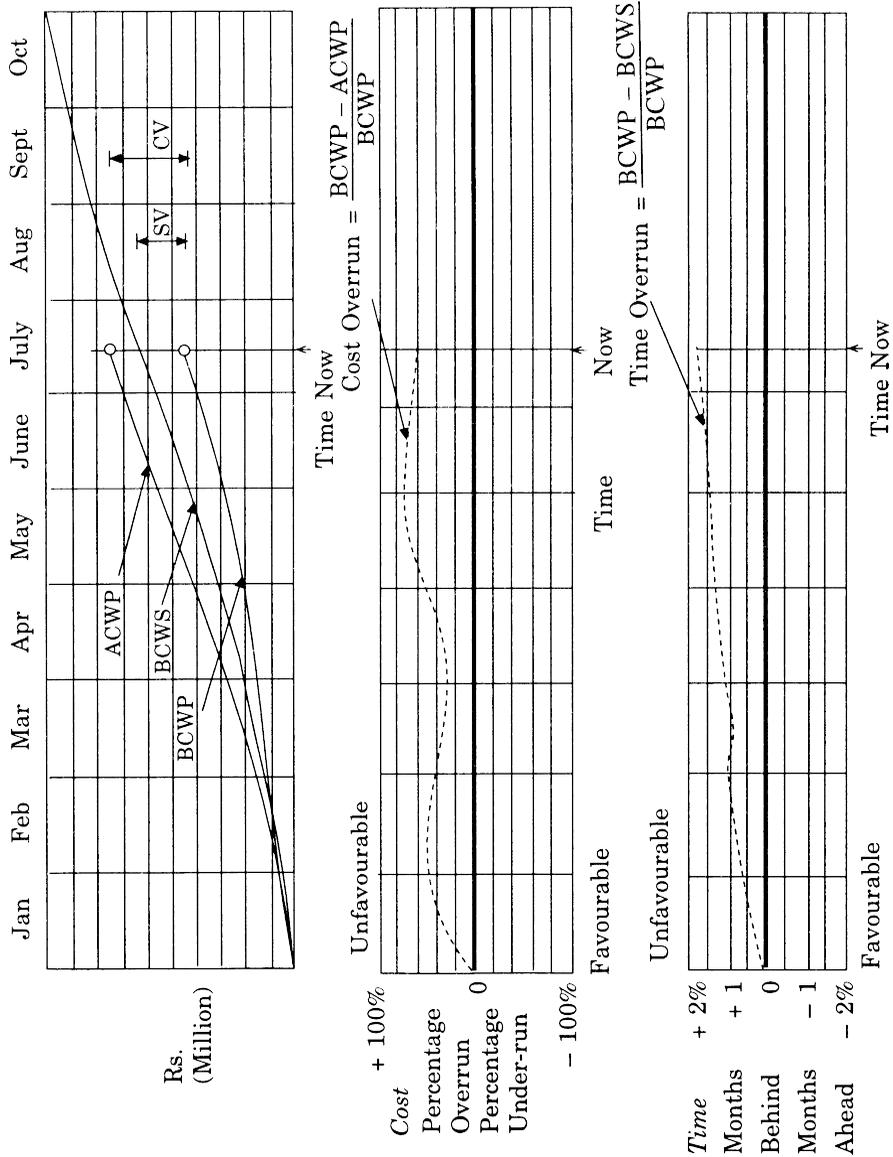
a. *Case I*: Assuming the future trend at the originally planned rate,

ABC Project	
Cost forecast at completion	$= AC + (BAC - EV)$
	$= 90 + (160 - 80.4)$
	$= 169.6$

b. *Case II*: Assuming that the future rate of progress will continue at the present trend,

ABC Project
Cost forecast at completion $= (BAC)/CPI$
$= (BAC) \times AC/EV$
$= 160 \times 90/80.4$
$= 179.1$

There can be situations where the originally specified time and cost objective are revised. For example, the original completion time of the project is extended or the agreed contract amount is increased. In such cases, forecasts corresponding to various situations can be worked out using methods given above.

15.5.6 Commonly Used Formulae for In-depth Earned Values Analysis

Earned Value Management (EVM) performance measurement define the points in the WBS at which measurement of control accounts will be performed, establish the earned value measurement techniques to be employed and specify tracking methodologies and the earned valaue management computation equiations for calculating project Estimate Aat Completion (EAC) forecasts to provide a validity chek on the bottom-up-EAC. The commonly used formulae are given in **Table 15.4**:

15.5.7 Example of Cost Performance and Trends Using Spread Sheet Software

There are many software that can be used to monitor the three EVS parameters (PV, EV and AC). Evaluation using Spread Sheet software 'Microsoft Excel' based on ABC Project at the end of 10th week is given in **Table 15.5** (formulae used are indicated against each).

❑ 15.6 EARNED VALUE MANAGEMENT SYSTEM: PAST, PRESENT AND FUTURE

Earned Value Management methods originated in U.S. in 1967 with Cost Schedule Control System Criteria (C/SCSC). It had a set of 35 Criteria that described the supplier-system characteristics for implementation of earned value system. However, it faced implementation problems and its application was limited to areas like "Defense" where it was mandatory.

The system was reviewed subsequently and in 1998 it became an American National Commercial Standard ANSI/EIA-748-1998US for implementing Earned Value Management Systems on projects and government contracts. In 1999, this standard was adopted by the US Department of

Table 15.4

Commonly Used Formuulae for Earned Value Analysis

Variances Formulae Cost Variance (CV)= EV – AC

- Schedule Variance (SV) = EV – PV

Indices Formulae

- Cost Performance Index = $\text{CPI} = \dfrac{\text{EV}}{\text{AC}}$

- Schedule Performance Index = $\text{SPI} = \dfrac{\text{EV}}{\text{PV}}$

Status in Percentage Formulae

- Schedule variance as a percentage of the PV = $\text{SV\%} = \dfrac{\text{EV} - \text{PV}}{\text{PV}} \times 100$

- Cost variance as a percentage of the EV = $\text{CV\%} = \dfrac{\text{EV} - \text{AC}}{\text{EV}} \times 100$

- Percentage completed on data date $= \dfrac{\text{EV}}{\text{BAC}} \times 100$

- Percentage spent on data date $= \dfrac{\text{AC}}{\text{BAC}} \times 100$

- Percentage of project scheduled to be achieved on data date $= \dfrac{\text{PV}}{\text{BAC}} \times 100$

Trends Formulae

- Estimated Cost At Completion $= \text{EAC} = \text{AC} + \dfrac{\text{BAC} - \text{PV}}{\text{CPI}}$, forecasting ETC at budget rate

- Variance at completion $= \text{VAC} = \text{BAC} - \text{EAC}$

Defense for project monitoring and control. This standard contemplates 32 criterias for operation of earned value management systems. These criteria are grouped under Organisation, Planning and Budgeting, Accounting Considerations, Analysis and Management- Reports, and Revisions and Data Maintenance. Some of the other advanced countries have come up with their own version of Earned Value System. These countries include Japan, Germany, Canada, Australia and Brazil.

Table 15.5

Cost Performance of ABC Project

Example EV Analysis: Summary of Cost Performance of ABC Project at the end of 10th week using Spread Sheet Software:

Inputs	Basic Data
Project Budget at Completion (BAC)	160 000
Actual costs on data date (AC)	50%
Earned value on data date (EV)	58%
Planned value on data date (PV)	$90 000

Processing Earned Value Data	Formulae	Evaluation
Actual costs (AC)	Basic Data	90 000
Earned value (EV)	Basic Data	80 000
Planned value (PV)	Basic Data	92 096
Cost variance (CV)	EV – AC	–10 000
Schedule variance (SV)	EV – PV	–12096
Cost performance index (CPI)	EV/AC	0.89
Schedule performance index (SPI)	EV/PV	0.87
Estimate at completion (EAC)	BAC/CPI	180 000
Estimate to complete (ETC)	EAC –AC	90 000
To-complete performance index	(BAC – EV) /(BAC –AC)	1.14
To-complete performance index	(BAC – EV)/(EAC –AC)	0.89
Variance at completion	BAC – EAC	–20 000

Note: Evaluation using Spread Sheet software such as 'Microsoft Excel' is based on Site Development Project Data. Formulae used are indicated against each.

Earned Value Performance Management System can be applied to any project that has a structured plan of work, a cost structure and a suitable data-gathering system. In general, it is well suited for those projects that have clearly defined objectives, well developed cost and time plans, formalised management structure, the right culture and support of the project management. The system can be used for cost planning and control by the sponsor's own organisation, contractor's internal cost control system and by both, combined on a mutually agreed cost accounting and reporting system.

The main benefits of the Earned Value Analysis are that it enables:

- Integration of WBS-OBS-CBS;
- Performance status evaluation;
- Cost and end-date forecasts;
- Insight into the problem;
- Improved financial control;
- Costs awareness;
- Management of risks; and
- Reduction in the performance measurement conflicts. But it needs a specially designed system and the skilled people to implement it.

In construction contracts, it is valuable to incorporate the EVM methodology for monitoring the time progress, cost reporting and control processes. The successful implementation of the method depends upon extensive and accurate documentation periodically to capture the planned and actual cost performance in relation to project schedules, using the computerised approaches like Excel software as illustrated in example above to simplify calculations.

APPENDIX O

Construction Contracts Cost Accounting Guidelines

❑ O.1   INTRODUCTION

Cost accounting is basically a service function designed to record systematically all transactions and to provide information to concerned persons for interpretation, use and decision-making. Accounting Standards are the principles and methods stipulated in a country to standardise the cost accounting practices. Accounting bodies throughout the world are striving to achieve a reasonable degree of uniformity in the accounting practices by prescribing accounting standards. The International Accounting Standard Committee (IASC) is the world body that formulates the International Accounting Standards. Accounting bodies of most of the countries are members of the IASC. The Institute of Chartered Accountant India is also a member of IASC. The Institute of Chartered Accountant in India has promulgated a number of accounting standards. It has prescribed a special standard for accounting construction contracts titled 'Construction Contract Accounting Standard 7 (AS7)'. The AS7 and IAS 11 are generally similar.

❏ O.2   NEED AND OBJECT OF CONSTRUCTION CONTRACT ACCOUNTING STANDARD

Construction activity differs from other businesses in many ways. The scope of construction contract varies by their size, the nature of construction activity undertaken and the field of specialisation. The diverse type of construction activities includes building constructions, highways, dams, bridges and utility installation and services. A construction contractor can be a general contractor, a specialist service contractor, sub-contractor, or a management contractor. The organisation structure, assets and capacity of a contractor vary with the type and size of the project. Each contractor may have a different estimation and accounting system but the common characteristics of contractors are that they bid to generate profit margin and are exposed to significance risks, change orders and disputes in the performance of the contract. Some contractors combine their efforts by forming joint ventures to undertake large-sized multi-tasking contracts. The nature of activity undertaken in construction contracts, the date at which the contract activity is entered into and the date when the activity is completed usually fall into different accounting periods.

The objective of Accounting Standard 7 (AS7 revised 2002) is to prescribe the accounting treatment of revenue and costs associated with construction contracts. Accounting principles and practices in Construction Contract Accounting Standard 7 (AS7) (revised 2002) and International Accounting Standard (IAS 11) are generally similar. Readers are advised to refer to AS7 and Indian Accounting Standard (IndAS 11) for in-depth study. The salient accounting principles prescribed in AS7 (revised 2002) are outlined in the subsequent sections. Accounting framework for Public-Private-Partnership (PPP) infrastructure projects is not covered in AS7 (revised 2002). PPP is proposed to be adopted in Indian Accounting Standard (IndAS 11).

❏ O.3   HOW IS CONSTRUCTION CONTRACT DEFINED?

Construction contract, as defined in the AS7 of the Institute of Chartered Accountant India, is a contract specially negotiated for the construction of an asset or a combination of assets that are closely interrelated or interdependent in terms of their design, technology and function or their ultimate purpose or use. A construction contract may be negotiated for the construction of a single asset such as a bridge, building, dam, pipeline, road, ship or tunnel. A construction contract may also deal with the construction of a number of assets which are closely interrelated or interdependent in terms of their design, technology and function or their ultimate purpose or use One example of such contracts include those for the construction of refineries and other complex pieces of plant or equipment.

For the purposes of Accounting Standard, construction contracts include:

- Contracts for the rendering of services which are directly related to the construction of the asset. Contracts for the destruction or restoration of assets, and the restoration of environment following the demolition of assets.

The construction contracts are of various types. These include contracts of fixed price, unit rate and cost-plus. The nature of these contracts is covered in **Chapter 2** of this book.

❑ O.4 COMBINING AND SEGMENTING CONSTRUCTION CONTRACTS

AS7 stipulates that the requirements of this Accounting Standard are usually applied separately to each construction contract. However, in certain circumstances, it is necessary to apply the Standard to the separately identifiable components of a single contract or to a group of contracts together in order to reflect the substance of a contract or a group of contracts.

If a contract covers a number of assets, the construction of each asset shall be treated as a separate construction contract when:

a. Separate proposals have been submitted for each asset.
b. Each asset has been subject to separate negotiation and the contractor and client/customer have been able to accept or reject that part of the contract relating to each asset; and
c. The costs and revenues of each asset can be identified.

A group of contracts, whether with a single client/customer or with several client/ customer, shall be treated as a single construction contract when:

a. A group of contracts are negotiated as a single package;
b. The contracts are so closely interrelated that they are, in effect, part of a single project with an overall profit margin; and
c. The contracts are performed concurrently or in a continuous sequence.

A contract may provide for the construction of an additional asset at the option of the client/customer or may be amended to include the construction of an additional asset. The construction of the additional asset shall be treated as a separate construction contract when:

a. The asset differs significantly in design, technology or function from the asset or assets covered by the original contract or;
b. The price of the asset is negotiated without regard to the original contract price.

❑ O.5 CONTRACT REVENUE: WORK DONE REVENUE, VARIATIONS IN CONTRACT WORK, CLAIMS AND INCENTIVE PAYMENTS

Contract revenue shall comprise of the earned value of the work done revenue agreed in the contract, variations in contract work, claims and incentive payments subject to the following:

*   The extent that it is probable that they will result in revenue; and
*   They are capable of being reliably measured.

Contract Work Done.   It is measured at the fair value of the consideration received or receivable. The measurement of contract revenue is affected by a variety of uncertainties that depend on the outcome of future events. The estimates often need to be revised as events occur and uncertainties are resolved. Therefore, the amount of contract revenue may increase or decrease from one period to the next. For example:

a. A contractor and a client/customer may agree variations or claims that increase or decrease contract revenue in a period subsequent to that in which the contract was initially agreed;

b. The amount of revenue agreed in a fixed price contract may increase as a result of cost escalation clauses;

c. The amount of contract revenue may decrease as a result of penalties arising from delays caused by the contractor in the completion of the contract; or

d. When a fixed price contract involves a fixed price per unit of output, contract revenue increases as the number of units is increased.

Change Orders.   A variation is an instruction by the client/customer for change in the scope of the work to be performed under the contract. A variation may lead to an increase or a decrease in contract revenue. The changes made in the specifications or design of the asset and changes in the duration of the contract are examples of variations. A variation is included in contract revenue when:

a. It is probable that the client/customer will approve the variation and the amount of revenue arising from the variation; and

b. The amount of revenue can be reliably measured.

Contractor's Claim.   A claim is an amount that the contractor seeks to collect from the client/customer or another party as reimbursement for costs not included in the contract price. Claims arise on account of client/ customer caused delays, errors in specifications or design, and disputed variations in the contract work. The measurement of the amount of revenue arising from claims is subject to a high level of uncertainty and often depends on the outcome of negotiations. Therefore, claims are included in contract revenue only when:

a. Negotiations have reached an advanced stage such that it is probable that the client/customer will accept the claim; and

b. The amount that it is probable will be accepted by the client/customer can be measured reliably.

Incentive Payments.   These incentive payments are additional amounts paid to the contractor if specified performance standards are met or exceeded. For example, a contract may allow for an incentive payment to the contractor for early completion of the contract. Incentive payments are included in contract revenue when:

a. The contract is sufficiently advanced and it is probable that the specified performance standards will be met or exceeded; and

b. The amount of the incentive payment can be measured reliably.

❑ O.6   CONTRACT COSTS: DIRECT COST AND INDIRECT COST

Contract costs shall comprise:

- **Direct Cost** that relate directly to the specific contract;
- **Indirect Cost** that are attributable to contract activity in general and can be allocated to the contract.

Direct Cost. that relate directly to a specific contract include:

- Site labour costs, including site supervision;
- Costs of materials used in construction;
- Depreciation of plant and equipment used;
- Costs of moving plant, equipment and materials to and from the contract site;
- Costs of hiring plant and equipment;
- Costs of design and technical assistance that is directly related to the contract;
- The estimated costs of rectification and guarantee work, including expected warranty costs; and
- Claims from third parties.

These costs may be reduced by any incidental income that is not included in contract revenue, for example income from the sale of surplus materials and the disposal of plant and equipment at the end of the contract.

Indirect Cost. may be attributed to contract activity in general and can be allocated to specific contracts that include:

- insurance;
- Cost of design and technical assistance that are not directly related to a specific contract; and
- Construction overheads.

An indirect costs is allocated using methods that are systematic and rational and are applied consistently to all costs having similar characteristics. The allocation is based on the normal level of construction activity. Construction overheads include costs such as the preparation and processing of construction personnel payroll. Costs that may be attributable to contract activity in general and can be allocated to specific contracts also include borrowing costs.

Costs that are specifically chargeable to the Client/Customer under the terms of the contract may include some general administration costs and development costs for which reimbursement is specified in the terms of the contract.

Excluded Costs. Costs that cannot be attributed to contract activity or cannot be allocated to a contract are excluded from the cost of a construction contract. Such costs include:

- General administration costs for which reimbursement is not specified in the contract;
- Selling costs;
- Research and development costs for which reimbursement is not specified in the contract; and
- Depreciation of idle plant and equipment that is not used on a particular contract.

Contract costs include the costs attributable to a contract for the period from the date of securing the contract to the final completion of the contract. However, costs that relate directly to a contract and

are incurred in securing the contract are also included as part of the contract costs if they can be separately identified and measured reliably and it is probable that the contract will be obtained. When costs incurred in securing a contract are recognised as an expense in the period in which they are incurred, they are not included in contract costs when the contract is obtained in a subsequent period.

Contract Securing Costs. Contract costs include the costs attributable to a contract for the period from the date of securing the contract to the final completion of the contract. However, costs that relate directly to a contract and are incurred in securing the contract are also included as part of the contract costs if they can be separately identified and measured reliably and it is probable that the contract will be obtained. When costs incurred in securing a contract are recognised as an expense in the period in which they are incurred, they are not included in contract costs when the contract is obtained in a subsequent period.

❑ O.7   RECOGNITION OF CONTRACT REVENUE AND EXPENSES

When the outcome of a construction contract can be estimated reliably, contract revenue and contract costs associated with the construction contract shall be recognised as revenue and expenses respectively by reference to the stage of completion of the contract activity at the end of the reporting period. An expected loss in the construction contract shall be recognised as an expense immediately.

In the case of a fixed price contract, the outcome of a construction contract can be estimated reliably when all the following conditions are satisfied:

- Total contract revenue can be measured reliably;
- It is probable that the economic benefits associated with the contract will flow to the entity;
- Both the contract costs to complete the contract and the stage of contract completion at the end of the reporting period can be measured reliably; and
- The contract costs attributable to the contract can be clearly identified and measured reliably so that actual contract costs incurred can be compared with prior estimates.

In the case of a cost plus contract, the outcome of a construction contract can be estimated reliably when all the following conditions are satisfied:

- It is probable that the economic benefits associated with the contract will flow to the entity; and
- The contract costs attributable to the contract, whether or not specifically reimbursable, can be clearly identified and measured reliably.

The recognition of revenue and expenses with reference to the stage of completion of a contract is often referred to as the percentage of completion method. Under this method, contract revenue is matched with the contract costs incurred in reaching the stage of completion, resulting in the reporting of revenue, expenses and profits which can be attributed to the proportion of work completed. This method provides useful information on the extent of contract activity and performance during a period.

Under the percentage of completion method, contract revenue is recognised as revenue in profit or loss in the accounting periods in which the work is performed. Contract costs are usually recognised as an expense in profit or loss in the accounting period in which the work is performed. However, any expected excess of total contract costs over total contract revenue for the contract is recognised as an expense immediately in accordance with paragraph 36.

A contractor may have incurred contract costs that relate to future activity on the contract. Such contract costs are recognised as an asset provided it is probable that they will be recovered. Such costs represent an amount due from the client/customer and are often classified as contract work in progress.

The outcome of a construction contract can only be estimated reliably when it is probable that the economic benefits associated with the contract will flow to the entity. However, when an uncertainty arises about the collectability of an amount already included in contract revenue, and already recognised in profit or loss, the uncollectible amount or the amount in respect of which recovery has ceased to be probable is recognised as an expense rather than as an adjustment of the amount of contract revenue.

An entity is generally able to make reliable estimates after it has agreed to a contract which establishes:

- Each Party's Enforceable Rights regarding the asset to be constructed;
- The consideration to be exchanged; and
- The manner and terms of settlement.

It is also usually necessary for the entity to have an effective internal financial budgeting and reporting system. The entity reviews and, when necessary, revises the estimates of contract revenue and contract costs as the contract progresses. The need for such revisions does not necessarily indicate that the outcome of the contract cannot be estimated reliably.

The stage of completion of a contract may be determined in a variety of ways. The entity uses the method that measures reliably the work performed. Depending on the nature of the contract, the methods may include:

- The proportion that contract costs incurred for work performed to date bear to the estimated total contract costs;
- Surveys of work performed; or
- Completion of a physical proportion of the contract work.

Progress payments and advances received from client/customers often do not reflect the work performed. When the stage of completion is determined by reference to the contract costs incurred to date, only those contract costs that reflect work performed are included in costs incurred to date. Examples of contract costs which are excluded are:

a. Contract costs that relate to future activity on the contract, such as cost of materials that have been delivered to a contract site or set aside for use in a contract but not yet installed, used or applied during contract performance, unless the materials have been made specially for the contract.

b. Payments made to subcontractors in advance for work performed under the subcontract.

When the outcome of a construction contract cannot be estimated reliably:

a. Revenue shall be recognised only to the extent of those contract costs incurred that are recoverable;
b. Contract costs shall be recognised as an expense in the period in which they are incurred.

An expected loss on the construction shall be recognised as an expense immediately in accordance with expected loss.

❑ O.8   RECOGNITION OF EXPECTED LOSS

When it is probable that total contract cost will exceed total contract revenue, the expected loss shall be recognised as an expense immediately. The amount of such a loss is determined irrespective of:

- Whether work has commenced on the contract;
- The stage of completion of contract activity; or
- The amount of profits expected to arise on other contracts which are not treated as a single construction contract.

❑ O.9   DISCLOSURE

An entity shall disclose:

- The amount of contract revenue recognised as revenue in the period;
- The methods used to determine the contract revenue recognised in the period; and
- The methods used to determine the stage of completion of the contract in progress.

An entity shall disclose each of the following for contracts in progress at the end of the reporting period:

- The aggregate amount of costs incurred and recognised profits (less recognised losses) to date;
- The amount of advances received; and
- The amount of retentions.

  Note: Retentions are amounts of progress billings that are not paid until the satisfaction of conditions specified in the contract for the payment of such amounts or until defects have been rectified. Progress billings are amounts billed for work performed on a contract whether or not they have been paid by the client/customer. Advances are amounts received by the contractor before the related work is performed.

An entity shall present:

- The gross amount due from client/customers for contract work as an asset; and

- The gross amount due to client/customers for contract work as a liability.

The gross amount due from client/customers for contract work is the net amount of:

- Costs incurred plus recognised profits; and
- The sum of recognised losses and progress billings.

The gross amount due to client/customers for contract work is the net amount of:

- Costs incurred plus recognised profits; and
- The sum of recognised losses and progress billings.

An entity discloses any contingent liabilities and contingent assets in accordance with IAS 37 *Provisions, Contingent Liabilities and Contingent Assets*. Contingent liabilities and contingent assets may arise from such items as warranty costs, claims, penalties or possible losses.

Controlling Project Time Schedule

Construction projects are time bound and all its activities are directed towards achieving the project's time objectives. In a complex project, where a large number of activities are performed at different places by different agencies or task forces, with each having its own scheduled targets, a small delay in a critical activity can affect many schedules. Delays can alter the planned level of resources and their mobilisation. Time overruns increase overheads, reduce planned revenue from sales, and create cash inflow problems. Delays in contracted projects can result in penalties and adversely affect the company's reputation. Delays also lead to confusion and conflicts.

Project time schedule control aims at the timely execution of work according to the planned schedule of project and applies corrective measures in case of time deviations. In its broader sense, time control implies control of the entire planning system as time is directly or indirectly related with all activities and project functions.

Time control refers to the process of monitoring the status of project time performance, updating project time schedule, managing deviations from the time schedule, and applying corrective measures and reschedule, if necessary, to complete the project within the stipulated time. The baseline for measuring and updating the activity time progress is the project master schedule of work. A What-if analysis highlights the various options that are available for timely completion of the balance work. Time compression and time crashing (by trading time with cost) techniques are employed to reduce time overruns. The progress review of project work at predetermined time intervals, reduces the communication gap between the project management and executing agencies. In this chapter, coverage of time control includes the following sections:

1. Time Progress Monitoring Methodology
2. What-if Analysis
3. Time Reduction Techniques
4. Critical Chain Method
5. Guidelines for reviewing time progress

6. Project Management Software Capabilities

The monitoring and controlling of time schedule can be speedily done using any project management software. **Appendix F** of **Chapter 6** outlines the capability of commonly used project management software. Appendix P to this chapter briefly covers Probability Distributions and Monte Carlo Simulation Application in predicting Project Completion Time using Oracle Crystal ball Software.

❑ 16.1 TIME PROGRESS MONITORING METHODOLOGY

Monitoring involves measuring the time progress activity-wise, updating progress on schedule charts, and analysing the implication of variations. Time monitoring starts with measuring of time and status of balance activities in the project's—completed or finished, in-progress and non-starter states. The baseline for monitoring time is the Project Master Schedule. Time monitoring of simple projects can be carried out directly reflecting the time progress of activities on the Project Master Schedule and then analysing the implications of deviations from the schedules. But, in case of complex projects, a critical examination of the Project Master Schedule is only feasible after network plans are updated and analysed, as the bar chart master schedule generally does not reflect the logical relationship of activities. Accordingly, time monitoring of complex projects can broadly be divided into the following three stages:

a. Measuring time progress of activities;
b. Updating the progress of activities on planning charts, i.e. networks and project time schedule; and
c. Analysing the implications of deviations of planned performance with actual   performance.

16.1.1 Measuring Time Progress of Activities

Measuring the work progress in terms of quantity of work done is a time consuming progress. Generally, it is done on daily, weekly or monthly basis, by the engineer-in-charge with the help of quantity surveyors and is recorded in the measurement books. The progress of work done and value of work is reflected quantitatively on monthly and cumulative basis in the contractor's advance payment application. But it does not reveal the activity being performed on a day-to-day basis. The commonly adopted method for determining time progress on a given date is to compare actual time elapsed since commencement of the activity with planned total duration of the activity.

Generally, an activity performance is expressed in percentage of time consumed (or work done) to its planned value. The method of determination of an activity progress varies with the nature of the tasks, i.e. repetitive and non-repetitive. The reporting of progress of repetitive tasks is based on the number of repetition of similar activities completed divided by total similar activities. In case of non-repetitive tasks, progress in percentage is generally determined activity-wise in terms of time performance, i.e. 'the units of time elapsed and the total time units that are required for completing the activity'.

16.1.2 Updating Project Timel Progress

A project is said to be proceeding smoothly as long as the activities are being performed as per the schedule. But at times, deviations from the schedule do occur. Some of the reasons for the delay could be inaccurate estimation for duration of activities, unforeseen climatic conditions, non-supply of materials on time, effect of changes in the scope of work, inadequate employment of resources, and labour strikes. On the other hand, some activities may need less time than the planned time. These time changes can be measured activity-wise from the current schedule of sub-project's work, and are recorded in the work progress reports. These reports include the actual data regarding the completed activities, the in-progress activities, and the future planning for the balance activities. In case of activity delays, the progress reports may also indicate extent of delay, availability of activity floats, and time required to complete balance work.

A time progress report does not make sense unless it is depicted pictorially on a network and/ or a schedule in a comprehensive form prior to time analysis. The method used for displaying up-to-date progress of activities on the planning charts corresponding to a given time is called updating. The procedure of updating and the symbols used vary with the technique adopted for planning projects. These activity updating methods are explained below:

The three states of activities in the network and schedule can be categorised as under:

- **Complete activity.** For completed activity, delete the duration and make it zero duration activity.
- **Partially Completed activity.** For partially completed activities, delete the existing duration and insert the expected duration for balance work.
- **Still-to-start activity.** For the remaining activities, examine their duration that is reflected in the network. Delete the original durations and insert the revised durations, if it needs to be changed.

Activity updating methodology. On the planning charts, the three states of activities can be depicted as:

- For completed activities delete the duration;
- For partially completed activities delete the existing duration and insert the expected duration for balance work;
- For remaining activities examine their duration reflected in the plan. Delete the original duration and insert the revised duration, if it needs to be changed; and
- For new activities visualised as a result of change in the work scope, incorporate these logically and write their duration.

The procedure for updating and the symbols used vary with the technique used for planning projects. See **Table 16.1**

Time Analysis of Updated Networks. It involves the following steps:

a. Update the activity status as above including the preceding lead or logic times if applicable.

Table 16.1

Updating Activity Progress

Activity Status	Updating Activity-on-Arrow	Updating Activity-on-Node
	CPM / PERT Networks	**PNA /PDM Networks**
Completed Activities	Delete the original activity duration and hatch the preceding event.	Put a double cross on the Node and delete the preceding implementation constraints like FS, FF, SF, SS. Revise the succeeding
In-progress Activities	Delete the original activity duration and write the estimated duration for balance work.	Delete the original activity duration and write the estimated duration for balance work. Put a single cross on the activity box.
		implementation constraints like FS, FF, SF, SS, where needed. (See Exhibit 16.1)
Non-starter Activities	If required, change the original duration to estimate revised duration for the activity as assessed on data date.	If required, change the original duration to estimated revised duration for the activity as assessed on data date.
Additional Activities	Insert activities with duration in a logical manner.	Insert activities with duration in a logical manner.

For repetitive projects, update the LOB Chart S Curves to highlight cumulative planned vs. actual progress.

b. Compute the Earliest Finish Time (EFT) in the network to determine the minimum time required for the completion of the remaining work.
c. Set the Latest Finish Time (LFT) equal to the project time objective in the network.
d. Time analysis of the updated network.

In the project management software, after the status data is updated, the PDM analysis is carried out automatically by the computer.

16.1.3 Manually Updating and Time Analysis of PDM Activity-on-Nodes Networks

In the precedence networks, activity box of the completed activity is double crossed and that of in-progress activity is shown with a single line across. The completed activities durations are deleted by double crossing activity boxes; for 'in-progress activities', original duration is deleted and the expected duration for balance work is inserted; and for 'nonstarter remaining activities', the revised duration (where necessary) is substituted in place of the original duration. Thereafter, new activities resulting from change orders are incorporated into the network.

But that is not enough. Unlike CPM/PERT networks, the precedence situational (constraints) logic also changes as time progresses. Therefore, in precedence networks, earliest start time of activity, its duration, and its precedence relationships, are scrutinised and the network is updated accordingly. The planners can also develop their own methodology for updating PDM networks.

Example 1:   Manually updating of the Precedence Network of Raft Construction Project at the end of 6th working day. The project is planned as shown in the **Exhibit 5.1**, reproduced as **Figure 16.1**.

Figure 16.1

Precedence Network of the raft of a Foundation
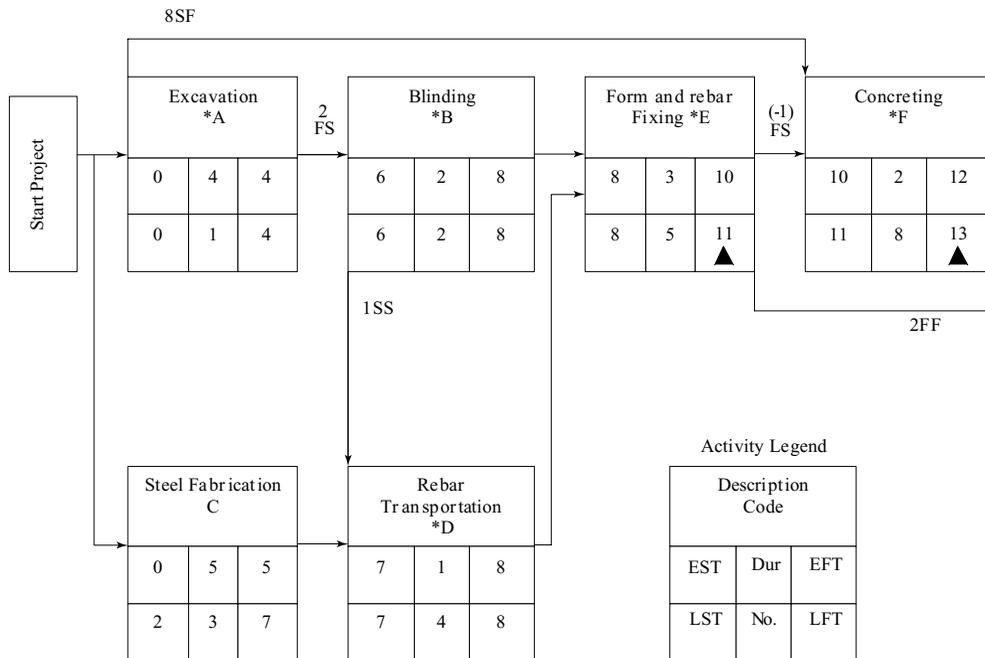
* Critical Activity
▲ Constrain imposed i.e. it must finish by the imposed time otherwise 'Form and rebar Fixing' for the next similar activity will be delayed.

On data date, the work has progressed as planned and logic is not changed, except duration of Blinding Activity B is expected to take one more day from the original duration. Updated Precedence Network at the end of 6th working day is shown in **Figure 16.2**.

1. Activities A and C are completed; therefore their boxes are double crossed as shown in the Updated Precedence Network.
2. Activity B duration is changed from 2 to 3 days and 2FS period is over therefore, it is underscored.

Figure 16.2

**Updated Precedence Network of the Raft of a Foundation
(Progress Status at the end of 6ᵗʰ Working Day)**
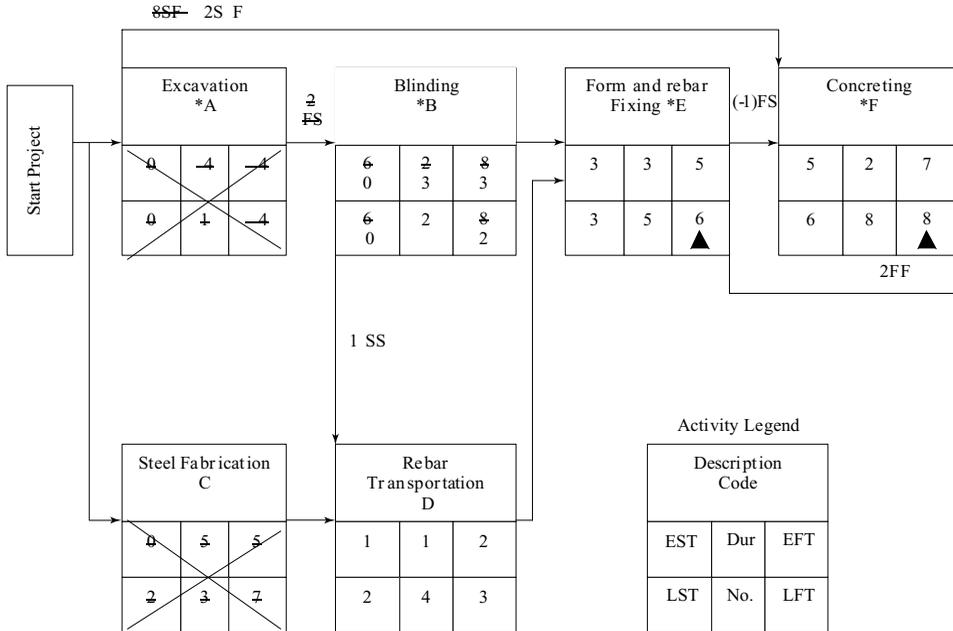
Note the following points from **Figure 16.2**:

3. Thereafter, subsequent unfinished part of network is analysed by time. Due to increase of the original duration by one, Activity D is not critical. Balance of SF at the end of the 6th day is 2.

4. At the end of the 6th day, no progress in Activity E and the succeeding week, with no change in original duration of activities or sequencing of work, FS between Activities A and B becomes 0 as the project marks end of the 6th day.

Example 2: Time Analysis of Updating Precedence Network. The status of the in-progress work packages of primary school precedence network as reported at the end of the 20th week from the start of construction is shown in **Table 16.2**.

The Primary School Construction updated time analysed network incorporating the above changes, is shown in **Exhibit 16.1**.

16.1.4 Manually Updating and Time Analysis of CPM/PERT Activity-on-Arrow Networks

Updating of activity-on-arrow, CPM/PERT networks. The three states of activities in the network can be depicted as under, where wiggly lines on arrows may or may not be drawn:

Table 16.2

Status of In-progress Work Packages at the End of 20th Week

Activity Code	Status	Duration for balance week	Precedence logic/Remarks
FW	Completed	—	—
FP	Completed	—	—
SG	In progress	2	Logic no change
SW	In progress	3	Logic no change
BP	Started in areas	7	Delete predecessor constraint 2FS
CJ	Still to start	5	Can start 2 weeks prior to completion of TP activity, i.e. tiling and painting activity

Exhibit 16.1

‡ Critical Activity
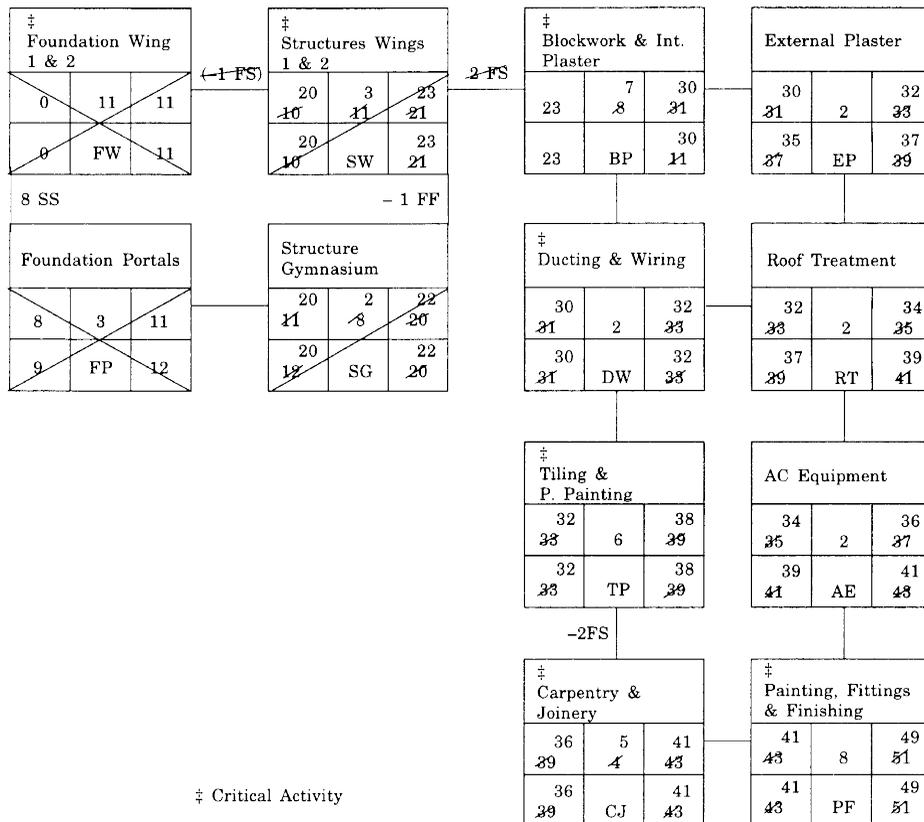
1. For completed activities, delete the duration and wiggly line can be drawn on the horizontal portion of the arrow. Completed activities and events are represented as:
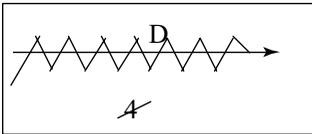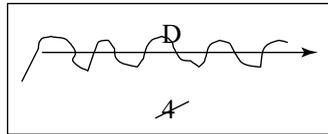
| Completed activity | Completed activity | Completed event |
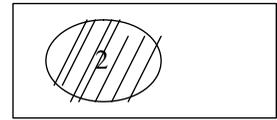
2. For partially completed activities, delete the existing duration and insert the expected duration for balance work. Preferably, draw a wiggly line on the horizontal part of the arrow in proportion to the work done. In-progress activity is represented as:
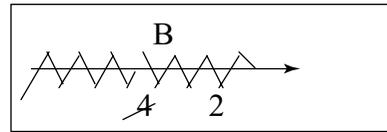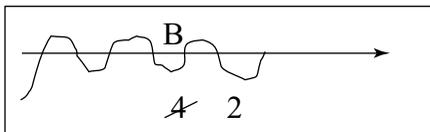
Partially completed CPM/PERT activity

3. For the remaining activities, examine their time duration reflected in the network. Delete the original durations and insert the revised durations if it needs to be changed. The revised duration of still-to-start activity is shown as:
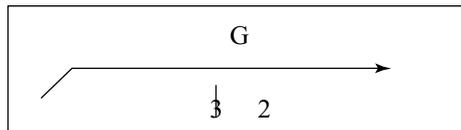
Still-to-start activity

Example: Time analysis of CPM updated network. The progress of project's work at the end of 6th week is tabulated in **Table 16.3**.

The above work progress can be transferred on the network using conventional symbols. The original and updated networks are shown in **Figure 16.3**.

16.1.5 Updating Line-of-Balance (LOB) Charts.

Construction projects of repetitive type, like multi-housing complexes are planned and scheduled using the LOB techniques. The main purpose of using the LOB techniques is to optimise the employment of resources and avoid interference in the progress of activities. The scheduling technique is covered in **Chapter 6**.

Table 16.3

Progress of Work of a Project at the End of the 6th Week

| S. No | Code | Activity | Duration | Work Done Value (in 1000$) | | |
		Description	Original	Balance of Work	Total	Percent
1	0-1	D	5	2	100	60%
2	1-6	E	2	2	10	Nil
3	6-8	F	1	1	5	Nil
4	5-8	G	3	3	15	Nil
5	0-2	A	4	0	20	100%
6	2-4	B	3	2	30	33%
7	0-3	C	2	0	20	100%
8	3-7	H	3	3	45	Nil
9	7-8	J	2	2	15	Nil
				Total	260	42.3%

Figure 16.3

CPM Updated Sub-networks
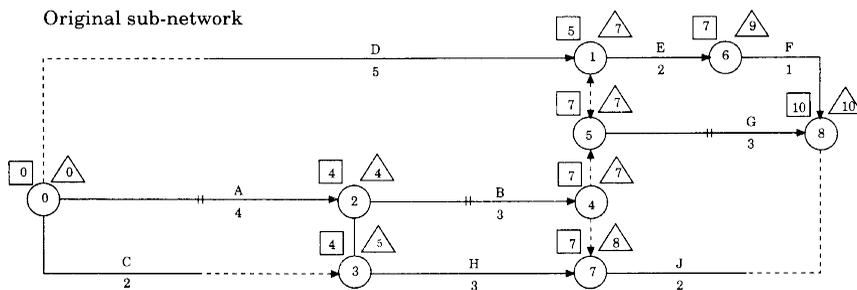
Updated Sub-network at the end of 6th Week the Completion Balance Activities of Takes upto 5 Weeks
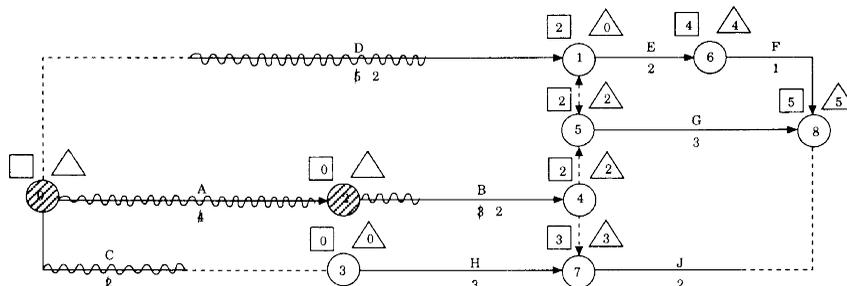
The LOB control chart is used to monitor the work progress. In this, the vertical axis represent the number of activities and the horizontal axis represents time, as shown in **Exhibit 6.9** drawn for controlling important finishing targets.

The LOB schedules are easily updated by plotting cumulative physical progress lines on the schedule of an LOB Chart (**Exhibit 16.2**). The actual progress line thus formed can indicate the following with respective to each repetitive activity:

Exhibit 16.2

LOB Updated Schedule
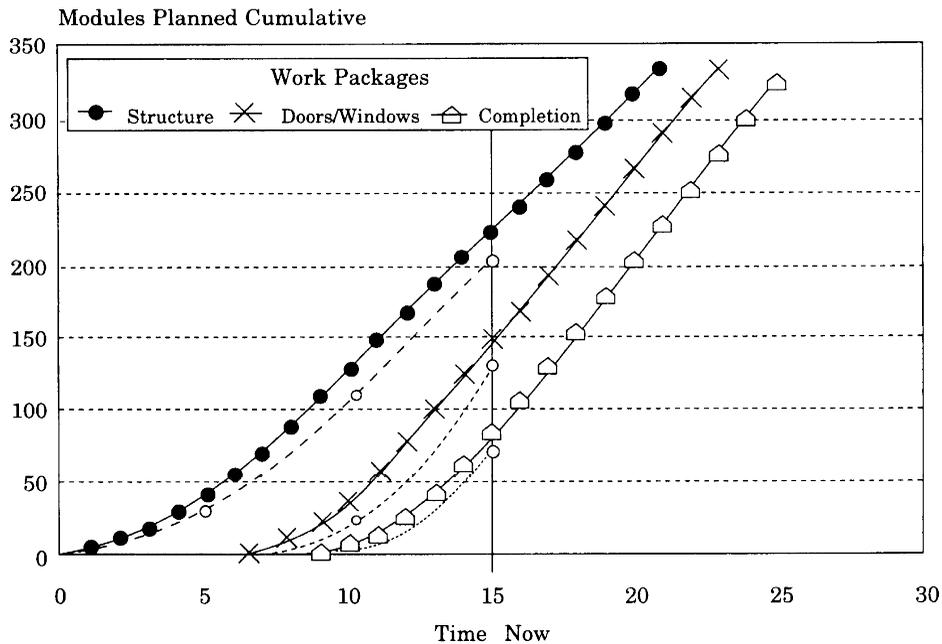
- Planned versus actual progress in terms of the number of units completed;
- Planned versus actual rate of progress;
- Risk of interference in progressing work of interdependent activities; and
- Forecast rate of progress for executing activities within the specified time targets.

The actual progress at the end of the month that is reflected in the LOB Tracking Chart determines variances from the planned targets. The activity progress beyond the LOB line shows progress ahead of schedule, while activity progress below the LOB line shows progress behind the schedule. The activities progress are analysed to determine the degree of criticality, such as the risk of interference in preceding and succeeding activities.

In case of work-packages with longer durations, say exceeding four weeks, the LOB chart can also show date-wise commencement and completion of these work packages' activities. But it is preferable to plot completed work packages so as to avoid congestion. Generally, where space

permits, the LOB tracking chart and the activity schedule chart are plotted on the same sheet and targets are tabulated, as shown in **Exhibit 6.10**.

16.1.6   Updating Bar Chart Schedule

Bar chart schedules are easy to construct, understand, communicate, and update. Bar charts are widely used for depicting the schedule of construction works. For simple projects, the bar chart schedules can be easily drawn but for complex projects, these schedules are developed using network analysis techniques. The method of scheduling work is covered in **Chapter 6**. Updating of a typical bar chart schedule involves the following steps:

- Draw time-scaled second bar below the scheduled activity;
- Depict its date of commencement and its time status; and
- Show the physical progress of activities as percentage of work completed either below/above the end of the progress bar. It can also be depicted graphically, as shown in **Exhibit 16.3**.

Note that the commonly used bar charts (other than time-scaled network plan) do not show an interdependent relationship among activities. Therefore, as a planning and controlling tool, it has limited use. However, Bar Chart is generally used at all levels for measuring and reporting progress, and its updating can be done by using commonly available project management software.

16.1.7   Analysis to Determine Contract Time Extension

The conventional methods do not provide a scientific way to determine the extension of the original contract time due to unforeseen delays and extra work deviation orders. Generally, the tendency is to total up delays. In certain cases, the claims of the contractor for delays that are due to the reasons beyond control may be accepted but no extension is awarded and no logical reasons are assigned to it. In the network based contract system, the Master Network and its schedule provide an index to assess the delays and analyse its effects on the completion of the project. Since the network logic and durations of activities are well established between both the parties, the implications of delays in the completion of critical/non-critical activities can be determined more accurately. For example, a delay in the commencement of a non-critical activity which is completed before its latest finish time (may be due to any reasons) does not entitle a contractor to claim for extension of time. But delay in critical activities due to non-supply of the materials under the client's supply or due to reasons that are beyond the contractor's control, need consideration for the time extension.

The procedure given below can form a reasonable basis for determining the extension of time:

Step I: List the delayed activities. Add acceptable period of delays (for causes beyond contractor's control) to the original period of affected activities.

Step II: List out the additional work as a result of change in activities and assessing their duration taking into consideration the reasonable lead time that is involved for procuring additional resources.

Exhibit 16.3

Activity	Progress Percentage (10% Per Column)										Duration	Working Period in Weeks
											Weeks	Jan 29 (01 02 03 04) — Feb 26 (05 06 07 08) — Mar 26 (09 10 11 12) — Apr 23 (13 14 15 16) — May 21 (17 18 19 20)
Site C	x	x	x	x	x	x	x	x	x	x	3	
Site H	x	x	x	x							17	
Site B	x	x	x	x	x	x	x	x	x	x	2	
Site G	x	x	x	x	x	x	x	x	x	x	4	
Site L	x	x									7	
Site E	x	x	x	x	x	x	x	x	x	x	4	
Site J	x	x	x	x	x	x					8	
Site F											3	
Site K											6	
Site D	x	x	x	x	x	x	x	x	x	x	5	
Site I	x	x	x	x	x	x	x	x	x	x	4	
Site A											9	

Time Now

Step III: Update the original network by incorporating additional activities that arise as a result of change, wherever applicable, in a lo gical manner and change the duration of delayed activities, as mentioned under Step I.

Step IV: Analyse the modified network to determine the minimum period that is required for the completion of the project.

Step V: Extension period can now be determined by computing the difference in project completion time between modified and original network.

Example: Consider the case of the pumping station project. The original master network of this project is given in **Exhibit 16.4**.

The original contract period was of 35 weeks. During the 34th week the contractor's claim for time extension was discussed. The client accepted the following delays for reasons (details omitted) beyond the contractor's control for extension of time.

1. *Approved Extension on account of time delays beyond contractors' control.*

Activity code	Description	Original duration	Accepted duration
0–1	*Excavation*	2	3
5–7	*Office electrification*	1	2
0–11	*Procurement of pumps*	20	25
12–13	*Installation of pumping sets*	1	2

2. *Approved Extension due to additional work ordered as deviation.*

   a. Office roofing activity 3-4: Duration to be changed from 1 week to 3 weeks.
   b. Excavation for pipe-line: Duration 2 weeks. The work can commence in the 31st week (the date of ordering work). Logic dictates that this should be undertaken after fixing suction and delivery pipes (Activity 13-14).
   c. Connecting rising mains including laying of pipe-line: Duration 3 weeks. Work to commence after fixing suction and delivery pipes and procurement of pipes.
   d. Procurement of pipe: Duration 7 weeks. It can commence at the time of ordering the extra work in the 31st week.

3. *Update revised network.* The revised updated network of the pumping station project incorporating delays and deviation orders, in a logical manner is shown in **Exhibit 16.5**. In the updated network, the revised project completion works out to be 41 weeks.
4. *Compute the extension permissible:*

Exhibit 16.4
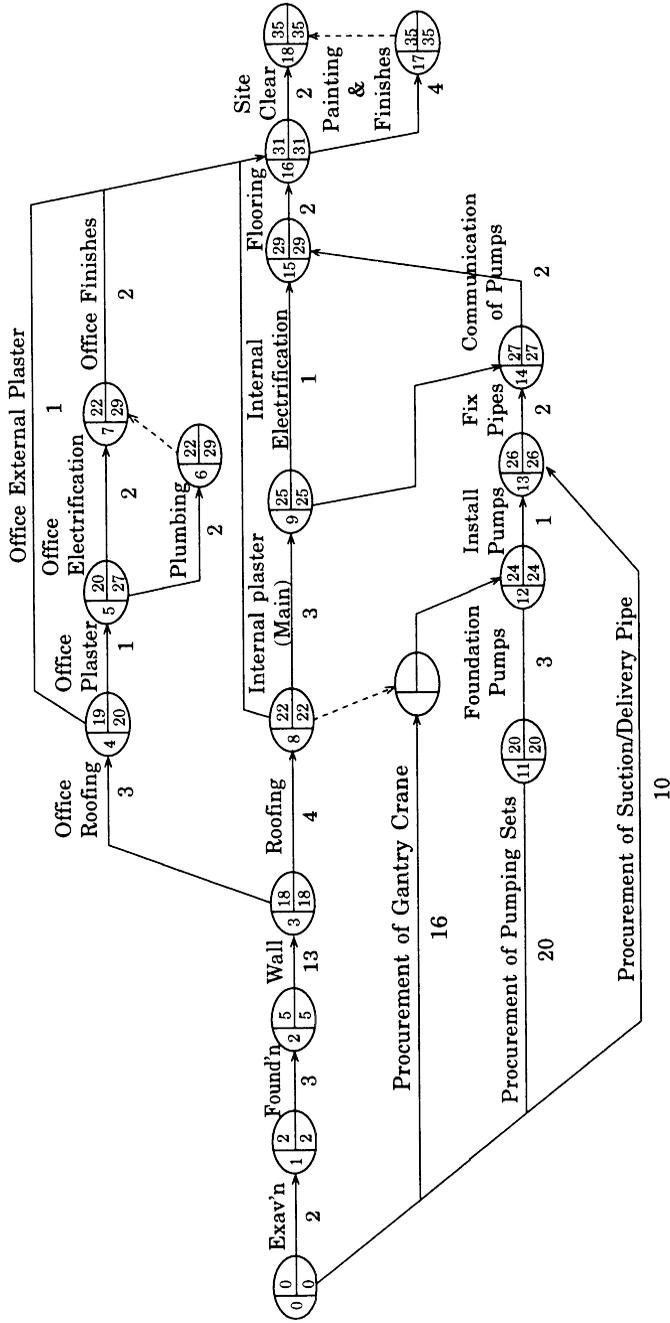
Exhibit 16.5

Original Time Analysed Network with Updated Durations
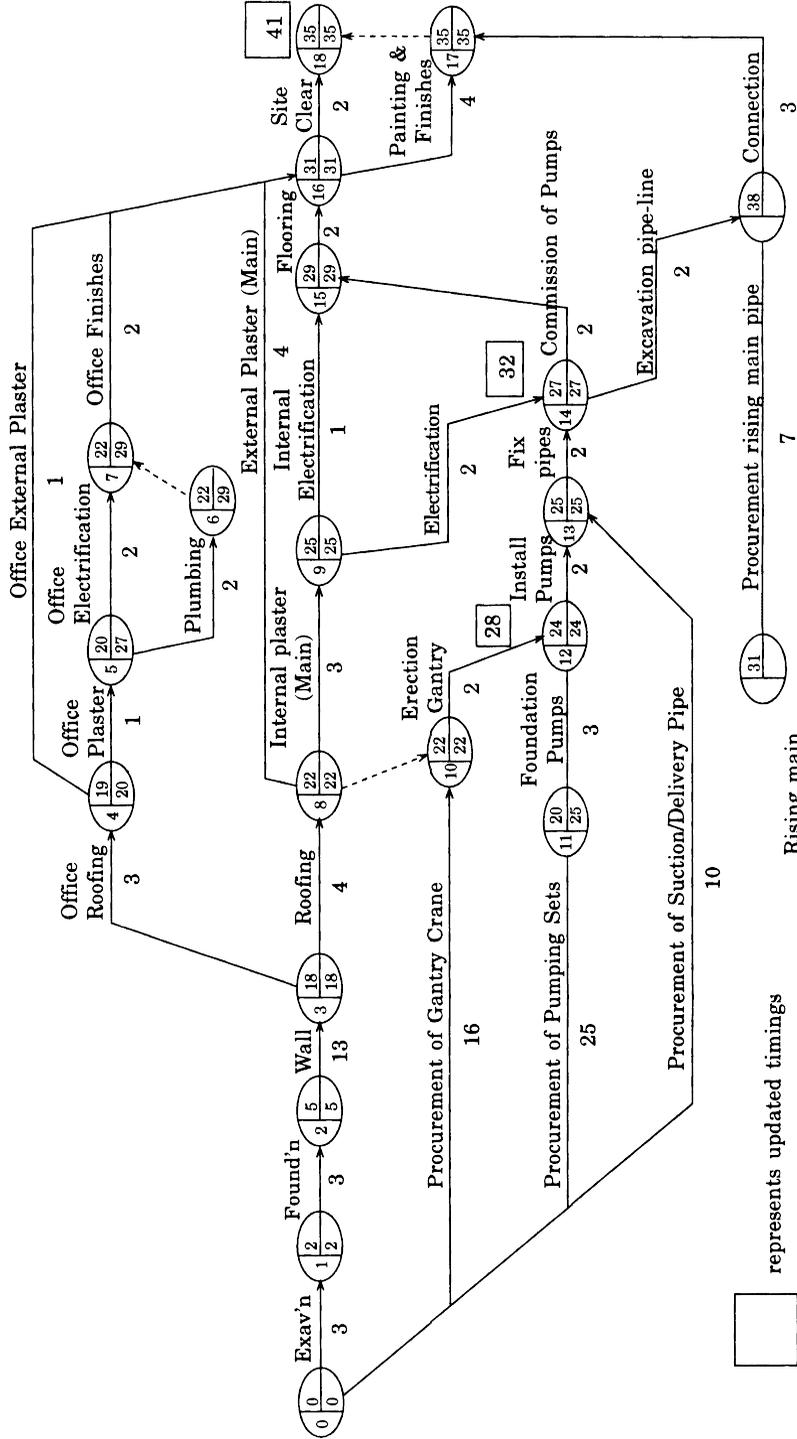
The estimated extension period = Revised completion period of contract – Original contract period
= 41 weeks – 35 weeks = 6 weeks.

❑ 16.2   'WHAT-IF' ANALYSIS

In the dynamic environments, especially in case of complex projects, a project may face situations, which tend to divert the project from its planned path. There may also be instances when the project management wants to alter the planned schedules for various reasons. During review of the project, questions may also be raised to devise course of action for achieving certain specific targets. All such cases start with the question 'What-if' and are followed by possible constraints, with the aim of deriving feasible alternate options to overcome time delays and its cost implications.

What-if analysis aims at exploring alternative approaches to meet imposed, anticipated, or desired constraints, with a view to provide information for making decisions regarding the incorporation of changes in the current work schedule. The project constraints that require What-if analysis can be broadly divided as:

- Time constrained What-if analysis; and
- Resources constrained What-if analysis.

16.2.1   Time Constrained 'What-if' Analysis

There are times when the scheduled dates get affected due to actual/anticipated situations, like weather conditions, breakdown of resources supply, equipment delivery schedule changes, or other reasons. Such cases, impose time constraints on following types of activities:
- Start not later than ___;
- Finish not later than ___;
- Start not earlier than ___;
- Finish not earlier than ___;
- Mandatory start on ___;
- Mandatory finish by ___;
- Schedule within the activity total float (zero total float or latest start time constraint) ___;
- Schedule within activity free float (zero free float constraints) ___; and
- Schedule activities at the earliest start time ___.

The implications of imposing time constraints can be studied by updating, analysing the time required for project network and re-scheduling activities. In case of activities having negative floats, the time compressions and/or the time crashing will have to be resorted for accomplishing the balance tasks within the scheduled time.

16.2.2   Resources Constrained 'What-if' Analysis

During work scheduling, vital resources are generally leveled to allow normal build up at the beginning of the connected tasks; a constant level of employment during the major period of execution;

and the normal tapering-off towards the end of the operation. These schedules also assume that resources should be available as and when required. But in actual practice, expensive resources are mostly limited. Constraints imposed on resources can be grouped as follows:

1. Time-limited resource availability: These are situations when sufficient resources are available during a limited period of time. In such cases, the work schedule may have to be revised for executing affected activities during the availability period of resources.
2. Resource-limited conditions: Such situations occur when there are insufficient resources to meet requirements of the scheduled work. Such situations comprises of rescheduling the work within limited resource constraints. The method of creating the work schedule under resource constraints is covered in **Chapter 6**.

❑ 16.3 TIME REDUCTION TECHNIQUES

The two commonly used techniques for reducing time overruns are 'compressing the critical path' and 'determining time-cost function for trading time with cost'. The time and cost function enables crashing of project time at the least cost.

16.3.1 Time Compression of Critical Path

Time compression is the process of reducing the project completion time without making any appreciable change in the cost of activities. It involves splitting (wherever feasible) of the critical activities into smaller activities, either by using different methods of execution without any appreciable change in resources or by changing to lower levels of activity details. Some of these smaller activities may form a chain of activities while others may be parallel. Generally, it is the parallel component of the critical activity that is responsible for compressing the project's completion time (see **Figure 16.4**).

Figure 16.4

**Part of the Network Showing the Significance of
Resolving an Activity 5–10 into Two Parallel Activities**
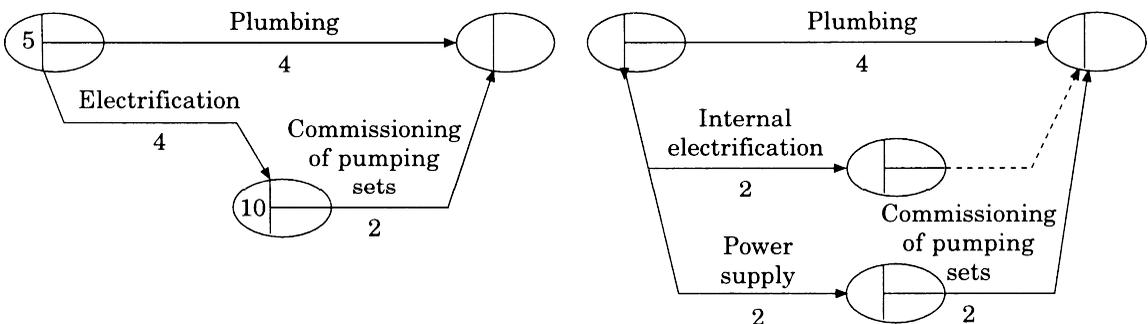
The network showing time compression of critical activities reduces the project duration from 41 weeks to 35 weeks, and the new critical paths resulting from time compression, are shown in **Exhibit 16.6**.

Time Compression of networks can also be examined by reviewing lead and lag logic and constraints imposed on the network.

16.3.2 Time Crashing Technique

Normally, completion period of a project should be determined from the network. The question of increasing the project duration beyond optimum completion time should not arise as it will add to the project's overhead cost. But some of the circumstances listed below may compel to set the project's completion time objectives lesser than the analysed completion time:

- To meet the management's need for the early completion of the project with acceptable cost to be paid for gaining time;
- To avoid delays which may attract heavy penalty or loss of goodwill;
- To venture on another project;
- To earn bonus for early completion if found feasible;
- To transfer the resources needed elsewhere; and
- To conform to a given resource's availability schedule.

The method of time crashing in network analysis aims at keeping the increase in cost for speeding the project from its optimum completion period to its minimum. In other words, it means buying time with the least price. Unlike traditional methods, where crashing implies speeding up all works, in case of networks analysis, crashing is carried out for selected activities which increases the project's cost.

The project cost curve which shows the pattern of cost variation with time, provides a ready-reckoner for assessing the increase in cost of the given project's duration. All crash point corresponds to the possible maximum time crashing.

The crashing cost can be determined from the project's cost curves. In addition, the tabulated data gives the information regarding the corresponding critical activities and their revised durations. For example, the implications of completing the project, as shown in **Figure 16.5** in 7 weeks are given below:

$$\text{Estimation economical cost for 9 weeks completion} = \$26\ 700.00$$
$$\text{Assessed cost for 7 weeks completion} = \$28\ 600.00$$
$$\text{Increase in cost due to crashing by 2 weeks} = \$1900.00$$

16.3.3 A Word of Caution

There are many gains which can be achieved by the early completion of the project. The early project completion can yield added revenue, early release of capital and facilities, and in some cases can save idle time expenses of machinery. The non-financial gains can be earning goodwill, boosting of reputation and raising of morale.

Exhibit 16.6

Original Time Analysed Network with Updated Durations

Figure 16.5

Time-Cost Trade-off Function
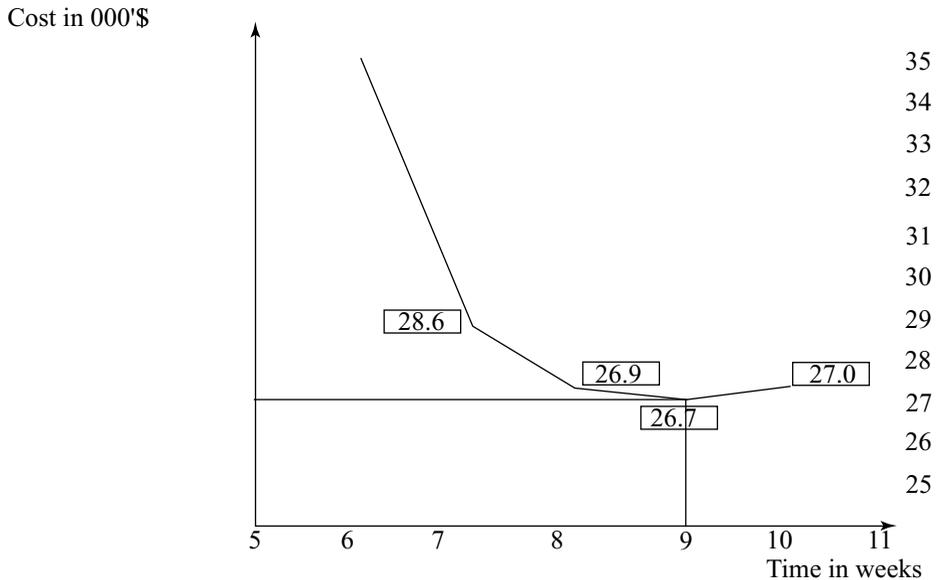
But the technique of minimising cost by crashing of activities, although mathematically feasible as explained, has great inherent practical difficulties. One of the main reasons is that it is not possible to predict activity cost-time data accurately. In addition, the advantage gained by economising the project cost is nullified by the fact that optimisation of resources becomes extremely difficult, resulting in increased cost and idle resources.

❏ 16.4 CRITICAL CHAIN PROJECT MANAGEMENT

16.4.1 Goldratt Critical Chain Project Management Concept

Completion of a project, with the initial specified constraints of time, cost, and quality is a rare occurrence which can be due to many reasons. A number of studies conducted on the project success factor have suggested various verifying solutions since no two projects are alike. In 1997, E.M. Goldratt   postulated a new approach to minimise time and cost overruns that addresses both, the human aspect and the technical approach in project management. It is based on the originator's bestselling novel which is known as *Critical Chain*. This approach is called *Critical Chain Project Management* (CCPM).

According to the Theory of Constraints (TOC), any system must have constraints; otherwise, its output would either increase without bounds or go to zero. To optimise this operation, Goldratt laid stress on identifying and managing the constraints optimally.

In Project Management, the core constraints are time, resources, and cost. The focus of Critical Chain Project Management (CCPM) is to identify the core problems that cause project failures (undesirable causes) and on how the project schedules can be managed.

Some of the undesirable causes identifies in CCPM are:

- Excessive activity duration estimates;
- Lack of activity positive variations;
- Failure to make use of positive variations;
- Failure to avoid delays caused by merging activity paths; and
- Low efficiency and loss of focus on project constraint caused by multi-tasking.

16.4.2 Main Undesirable Causes

Excessive activity duration estimation.   Initially, tendency of the duration estimators is to first calculate expected duration estimate corresponding to around 50% confidence level using one-time, three-times, or other methods. Thereafter, they add contingency time to allow for unforeseen safety/reserves that is expected and is corresponding to around to 80%–95% confidence level in order to make it a highly probable performance target. Thus, traditional duration estimation approach includes hidden safety factors in each activity to cater for Murphy's Law, which states that: "if anything can go wrong, it will." This makes executives feel comfortable but it results into many harmful consequences, such as:

1. *Parkinson's Law comes into action*. The work effort expands to accommodate the additional time. People simply adjust the level of effort to keep occupied for the entire duration.
2. *Level of effort generally followed the 'Student Syndrome'*. Little effort is made by the student during the initial days of assigned homework and when the safety period is past, student starts working with high speed which sometimes leads to overruns from the original estimated date for submission of the assignment.
3. *It erodes hidden safety reserves*. The project is denied the benefit of the safety time included in duration estimate of an activity, which would have yielded a positive variance, if the work is executed at a high speed as done during the final days of 'Student Syndrome'. In fact, excess activity duration wastes safety time which is catered to protect against effects of Murphy's Law.

Multi-tasking.   Multi-tasking is the process of simultaneously conducting multi-project activities. It is equivalent to dividing time between the multiple activities/projects. Multi-tasking creates the following adverse effect on the project:

1. It reduces efficiency as there is always wastage of time when a person switches attention from one task to another. Thus, it extends the project duration in case a critical chain activity is evolved in multi-tasking.

2. Multi-tasking creates an environment where there is likelihood of losing focus for actions related to vital delivery that are directed at accomplishing project activities. Median value implies that there is an equal likelihood that the tasks will either under-run or over-run. The median figure is often on the optimistic side of the CPM's one-time estimate and PERT three-times estimate.

16.4.3 Planning Critical Chain Project

Procedure

Step 1: Clearly state the objectives of the project.
Step 2: Determine the tasks needed to meet them and their originally assessed duration.
Step 3: Determine the logical relationship between tasks.
Step 4: Reduce activity duration say by 30%–40% eliminating safety margins.
Step 5: Identify the critical chain.
Step 6: Insert project buffer (PB) in critical chain and the feeding buffers (FB) in non-critical.
Step 7: Include critical chain schedule including PB and FB (balance) buffers by leveling resources with latest start date schedule, within resources leveling constraints.
Step 8: If necessary go back to an earlier step and revise the plan.

Note:

1. The critical chain is that set of tasks which determines overall project duration taking into account both precedence and resource dependencies.
2. Improvements along the critical chain will most likely result in improvements to the project as a whole but improvements elsewhere will not.
3. The feeding buffer protects the critical chain from fluctuations on feeding non-critical tasks and provides the possibility for critical chain tasks to start early.
4. The resource buffer protects the critical chain from lack of availability of required resources and also provides the possibility for critical chain tasks to start early.

Example: Consider the XYZ project. The critical chain network and schedule can be developed step-by-step as follows:

Objective. Project to be completed in 20 weeks with 4-machines and by working 6-day/week calendar.

Task, original duration and logic. The project has 12 tasks labeled from A to L. Task duration and PDM network is shown in **Figure 16.6**.

Reduced activity duration by 50%. This eliminates safety margins and facilitates changing week of 5-day duration (with one extra day as reserve) to six working days.

Figure 16.6

XYZ Project Critical Chain
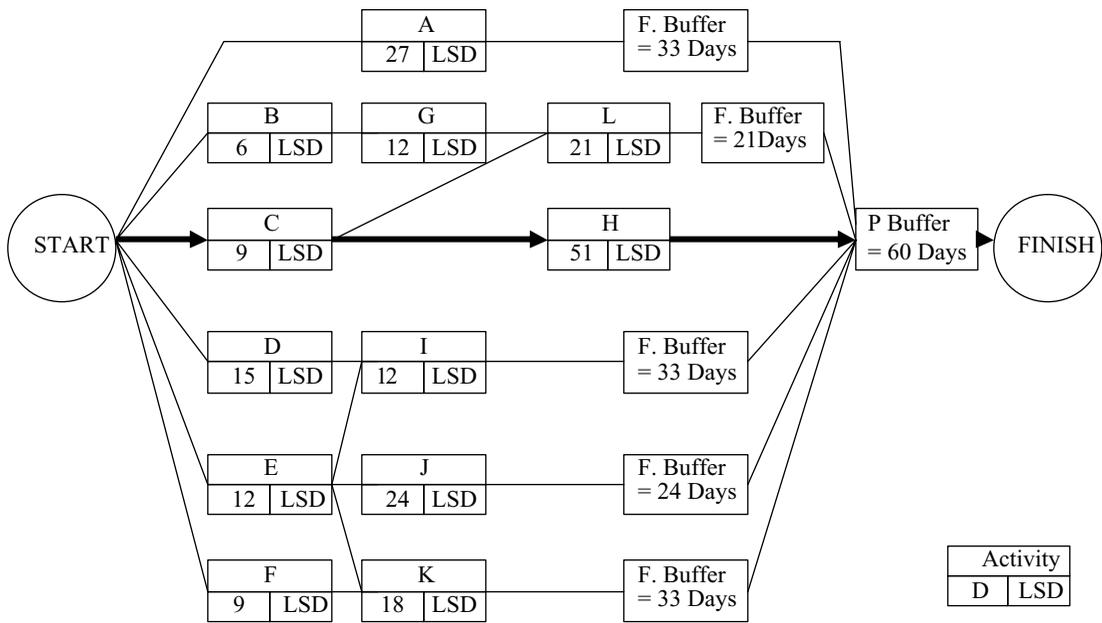
ABC PROJECT CRITICALCHAIN

D = Duration in Days
LSD = Latest Start Date

Identify the critical chain and insert project buffer and feed buffers.   The critical path and buffers when combined define the critical chain. Thus, PB acts as absorber, is placed prior to the terminal point to protect the target end-date against overruns in the critical chain (see **Figure 16.6**).

Critical chain-based schedule.   The critical chain schedule developed by levelling resources, including PB and feeder (balance) buffers, with the latest start date schedule, within availability constraints is charted in **Table 16.4**. It shows the sequence in which the tasks are to be performed. The critical path and buffers combine to define the Critical Chain. Thus PB acts as a shock absorber, placed prior to the terminal point to protect the target end date against overruns in critical chain tasks. The FB in non-critical chains safeguard the critical chain against delays from non-critical chain tasks and their merger effect.

   Resources buffer can also be added to ensure that critical chain resources are available as and when required. The PB of 10 weeks is not shown on the chart. The work is scheduled with tasks starting at their LST. It enables reduction in work-in-progress inventory; expenses are occurred as late as possible. There are less teething troubles and the executives can have better focus on the critical chain.

Table 16.4

XYZ Project: Levelled Resources Critical Chain Schedule

No.	Activities	Working Weeks with 6–Day Calendar									
		1	2	3	4	5	6	7	8	9	10
1	Task C, H	C	H								
2	Task B, G, L	B	G		L						
3	Task E, J	E		J							
4	Task F, K							F	K		
5	Task D, I	D			I						
6	Task A					A					

4	4	4	4	4	4	4	4	4	4	4	5	4	3	3	3	3	3	2	2

Machines Requirement Schedule

16.4.4 Multi-Project Plan Development

A multi-project environment have multiple single projects running concurrently, with each other that compete for scarce resources. Scheduling and controlling of multi-projects involves the following steps:

- Treat each project separately as a single project;
- Stagger projects by optimising available corporate resources;
- Create a corporate capacity buffer; and
- Control time and scare resources during implementation.

In multi-project plan development, Goldratt used the concept of drum resources for referring to key critical resources around which the project is synchronised. In other words, drum is the constraint of the system that sets the pace in the system. In a multi-project environment plan, each project identifies the critical resource, creates the critical resource schedule based on confirmation of available constraints (drums), and interest project and feeding resources buffers into each project logic diagram.

16.4.5   Buffers Management is the Key in Controlling Performance

Due to uncertainty, buffer management does not assign scheduled start and finish dates nor does it lay stress on time and cost variances. Instead it monitors the buffer status and its actions are dependent the extent of the buffer that is consumed. Generally, it sections the buffer status into three equal categories

Green Zone: No action	Yellow Zone: Examine various options.	Red Zone: Act to derive out the buffer penetration

- Take no action. if the penetration is in the green zone
- If the penetration enters the yellow zone, assess the problem and think about possible courses of action
- Act, if the penetration enters the red zone. These action plans should involve ways to finish the uncompleted tasks earlier in the chain or ways to accelerate future work in the chain to bring the buffer penetration back out of the red zone.

Note:

a. Buffers protect the project completion date and the critical chain.
b. Buffers can be used to look ahead and predict the effects of schedule disruptions on the project as a whole. This ability to look ahead gives more time to fix problems.
c. Using buffers, managers can have more confidence in their decisions and in their ability to justify decisions. This means they can be more productive.
d. Buffers enable undertaking of high-risk tasks as early as possible.
e. Buffer management helps to avoid frequent re-scheduling.

16.4.6   Merits and Limitations of CCPM

Merits

- Promoters of CCPM maintain that its application has resulted in early completion of some projects;
- CCPM provides a conflict free environment to the project team as compared to the tension created due to fixed time schedules and variances;
- Executives have an effective tool in the form of a buffer for making decisions;
- Investment and work-in-process are minimised; and
- Task priorities are well-defined.

Limitations

CCPM concept is still controversial due to the following reasons:

1. It is difficult to estimate the median value of activity duration as advocated in critical chain management.
2. Taking away 'entire safety margin' out of activity duration can create a negative attitude for someone who is unable to complete the job within the assessed duration.
3. The basic assumption that all resources shall be in position for starting of an activity and there will be no other bottleneck is questionable.

16.4.7   Critical Path Project Management vs. Critical Chain Project Management

Project time schedule is the baseline for controlling project's time, resources, and costs. It helps Project Manager to prevent undesirable time delays, cost overruns, and risks in the project. Both Critical Path Project Management (CPPM) and Critical Chain Project Management (CCPM) make use of the network concept with deterministic and probabilistic estimation approaches in activity duration. Both are helpful in project planning, monitoring, and controlling of time, resources, and costs, however, their planning, scheduling, monitoring, and controlling approaches are different.

CPPM determines the shortest time to complete the project and its critical activities are on the longest duration path through a network of activities. In this technique, each activity can be defined by its duration and floats are determined by activity timings (EST, EFT, LST and LFT). CPPM aims at starting all critical activities at EST. In this technique, especially in case of construction projects, project schedules are generally optimized for utilisation of scarce resources. CPPM enables determining of time-cost trade-offs and reducing risk. Its short comings are time overruns, lack dependencies of resources, and its critical path can change during execution. CPPM is being employed by most of the construction projects' organisation, since it was developed by DuPont Corporation in 1957.

CCPM is based on resource constrained situations, which effectively make use of Buffers (FB and PB) thus, avoiding time overruns and reducing wastage of resources. CCPM helps to safeguard against the Parkinson's Law, Student Syndrome and Multi-Tasking. It modifies the project schedule to account for limited resources. The critical chain concept was coined by Eliyahu Goldratt. It is said that CCPM was successfully implemented by the US Navy, Lucent, NASA, US Air Force, Philips, and many other organisations.

In short, both the CPPM and CCPM, as techniques for planning, scheduling, and controlling have merits and shortcomings but in case of construction projects, which are generally executed through contract(s), CPPM is being universally used (Section 1.6.3). However, CCPM can be effectively employed in construction projects that are being executed departmentally and not through contracts. Overall, planners of construction projects should refrain from being liberal with activity duration estimation so as to create a project buffer.

❑ 16.5 GUIDELINES FOR REVIEWING TIME PROGRESS

Activity duration and logic are not rigid. Some odd activities may be completed earlier than the scheduled dates, whereas, few others may be delayed. There is inherent overlapping in the logic of activities, and in some rare cases, succeeding activities may start earlier than the preceding activities. The updating methodology, covered above, brings out the deviations from the current project master schedule. The extent and implications of deviations are considered under 'review', which is carried out jointly by the project manager along with the executing agencies at pre- determined time intervals during the project's execution phase.

16.5.1 Aim of Review

Review involves the critical examination of the work progress with a view to make decisions for achieving specified objectives. The review process looks ahead rather than getting bogged down in conducting postmortems of past occurrences. A project review acts as an effective tool for co-ordinating and controlling the common objectives between the client and the executing agencies.

The scope of the review process can vary from a mere time progress updating exercise to the other extreme of performance analysis of the time, cost and quality objectives. Generally, the review should be confined to the time performance monitoring and related problems of resources and cost changes necessary to achieve the pre-determined agreed objectives.

16.5.2 Stages in Review

Reviewing of the work progress can proceed along the following lines:

1. Presenting updated current work program and sub-networks (as applicable) shown as completed, in-progress, and still-to-start activities together with start and completion dates.
2. Comparing the actual progress of work-package with its base line schedule and costs as per the project master plan.
3. Examining what can be done to neutralise time and cost overruns. Some of the options are:

   a. Time compress schedule without any appreciable increase in cost to shorten time by increasing resources of long duration critical activities; and splitting up sequential critical activities into parallel components.
   b. Time crash the critical path to reduce balance completion period by using alternate methods of construction involving minimum increase in overall project cost.
   c. Explore new methods of reducing costs within agreed specifications and time constraints.

4. Re-planning and re-scheduling balance works, if necessary, to ensure completion of the project on time.
5. Studying the emerging critical and near critical activities to anticipate problems and device means to overcome them.

6. Checking the resources at site to see if adequate resources are available to execute the scheduled work and to verify that additional resources, when required, shall arrive on time.
7. Evaluating the project cost status and updating forecasts for the future resources and costs for the remaining works.
8. Verifying the health, safety, and security measures to prevent mishaps.

Frequency of updating and reviewing will depend upon a number of factors, such as degree of control, purpose of the project, magnitude of work, phasing of work, and so on. There can be no rigid rules laying down the period after which the network and schedule should be updated and reviewed. Frequency of updating and the review can be specified either as a percentage of project completion time or in terms of regular time interval. As a thumb rule, for medium-sized construction projects, the following can be taken as a guide:

- Frequency of updating-weekly; and
- Frequency of review-monthly.

A review enables the project manager to make decisions concerning the actions that should be taken to overcome the anticipated time and cost overruns. Some of the decisions can be made on the spot during the review meeting, while others may need further time to analyse the implications.

It is emphasized that during the review the project manager is to produce a workable solution for future course of actions. This solution must take into consideration the varying interests of the executing agencies and the action plan should be acceptable to them. The review should look ahead to explore alternate ways of executing work to save time and costs rather than diagnosing historical mistakes that resulted in delays. The project manager should avoid discussions regarding responsibility for time and cost overruns as these lead to conflicts and contractual disputes.

APPENDIX P

Probability Distributions and Monte Carlo Simulation to Determine Project Completion Time

❑ P.1   INTRODUCTION AND SCOPE

Uncertainty during project implementation is a common feature. A project encounters uncertainty with regards to duration of activities, estimated cost, availability of various resources, and deviation in the project baseline plans. We cannot be sure of the actual value in the initial stages of the project. We can simply predict these using probabilities. Probability aids in quantifying uncertainties. The probability finds wide applications in network analysis, Monte Carlo Simulation for time and cost trends evaluation, probabilistic decision networks, and project risks management. Probability is the chance of a specified event occurring and it can take a value between zero and one. In general there are two ways of obtaining the probability i.e. objective or experimental based approach and subjective approach:

a.   **Objective or experimental based approach.** It is based on observed past data or frequency of occurrences of repeatable events or from a visible symmetry such as the rolling of a coin or dice.
b.   **Subjective approach**. It is based on personal opinions or judgement of experts about the occurrence of an event or outcome. Subjective probability is of two types i.e. Delphi and Nominal Group approaches. This approach is generally used for determining probability distribution functions.

The focus of this Appendix is on introducing probability and its application in project completion time. It briefly covers Probability Distributions and Monte Carlo Simulation Application in predicting Project Completion Time using Oracle Crystal ball Software. The project probability assessment tools and techniques are outlined in **Chapter 17**.

   For in-depth study, readers should refer to standard books on 'Applied Probability' and Simulation Software like Oracle Crystal Ball.

❑ P.2   PROBABILITY DISTRIBUTIONS

P.2.1   Types of Distributions

The method used to simulate a system model is based on the use of random numbers. A variable which assumes different numerical values as a result of random experiments or random occurrence

is known as a random variable. Random number has an equal probability of selection. Random numbers are numbers selected in such a manner that every number has an equal probability of being drawn.

If the random variable can assume any value within a given range, it is called a *continuous random variable*. If the random variable can assume only a limited value, it is called a *discrete random variable*. The probability distribution gives an indication of the likely value of random variable and the chances of occurrence of the various values. In case of uncertainty, the concept of expected value of a random value is used. The expected value is the mean of a probability distribution. This mean is calculated as the weightage average of the values that the random value can assume.

Probability distribution varieties run into hundreds relatively few are employed in project management. The important distributions can be categorized as under:

Continuous distribution	**Discrete distribution**
Normal	Binominal
Rectangular	Poisson
Exponential	Uniform
Triangular	
Beta	

A distribution gets defined when its equation, mean and standard deviation are known. In subsequent paragraph, while outlining probability distributions following notations have been used:

$$
\begin{aligned}
x &= \text{the random variable, having no bias.} \\
f(x) &= \text{the probability function} \\
a &= \text{minimum value} \\
b &= \text{maximum value} \\
m &= \text{mode (most likely value)} \\
\mu &= \text{mean} = E(x) = x \\
v &= \text{variance} = \sigma^2 \\
\sigma &= \text{standard deviation} \\
E &= \text{expected value}
\end{aligned}
$$

P.2.2   Commonly Used Basic Probability Distributions and Applications

P.2.3   Basic Probability Distributions' Mathematics

Normal Probability Distribution.   Normal distribution is Symmetrical, Uni modal, Extends from $-\infty$ to $+\infty$ and is defined by two parameters: μ and σ. Total area under the curve always equals 1.

Standard normal distribution values are given in **Chapter 4**.

Shape and Parameters	Applications
Normal Normal *Mean Standard Deviation*	The normal distribution is the most important distribution in probability theory because it describes many natural phenomena. Decision-makers can use the normal distribution to describe uncertain variables such as forecasting project completion time and cost, inflation rate or the future price of gasoline.
Triangular Triangular Minimum, Maximum, and Most Likely.	The triangular distribution describes a situation where you know the minimum, maximum, and most likely values to occur. For example, you could describe the activity duration in three times estimate in terms of the minimum, maximum, and most likely duration.
 Uniform Minimum and Maximum	In the uniform distribution, all values between the minimum and maximum occur with equal likelihood.
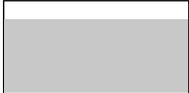
Uniform Distribution.   The possible outcomes are equally likely. Probability is the same in any small sub interval of a specific interval and zero everywhere else.

Triangular Distribution.   Three possible outcomes can be called: a, m and b. Possible outcomes are equally likely.

Beta PERT Distribution.   It is a continuous distribution constrained to a finite interval of possible values. It can be symmetrical, skewed to the right or skewed to the left.

P.2.4   Summary Probability Distribution application in activity duration estimation

Formulae for estimation of approximate mean and standard deviations of these probability distributions are given in below:

The above formulas are approximations only and can be used for practical purposes. Readers may refer to standard books on statistics to understand these probability distributions and calculate their theoretical mean, variance and standard deviations.

Probability Distributions Approximate Statistics of Simplifying Calculations

Statistics	Normal	Beta PERT	Triangular	Uniform
Expected Value or mean	$(a + b)/2$	$(a + 4m - b)/6$	$(b + m + a)/3$	$a + (b - a)/2$
Variance $v = \sigma^2$	$(b - a)^2/36$	$(b - a)^2/36$	$[(b - a)^2 + (m - a) \times (b - m)]/18$	$(b^3 - a^3)/[3 \times (b - a)]$ $- (b - a)^2/4$
Standard Deviation, σ	$(b - a)/6$	$(b - a)/6$	$\sqrt{v}$	$\sqrt{v}$

Note: a = Optimistic value, b = Pessimistic value, m = Most likely value, v = variance s = standard deviation

Figure P.1

where x = Mean Time (expect time t^2)
σ = Standard deviation

Normal Distribution Curve

$$y^2 = \frac{1}{\sigma\sqrt{2x}} \, e^{-(x-x)2/2\sigma^2}$$
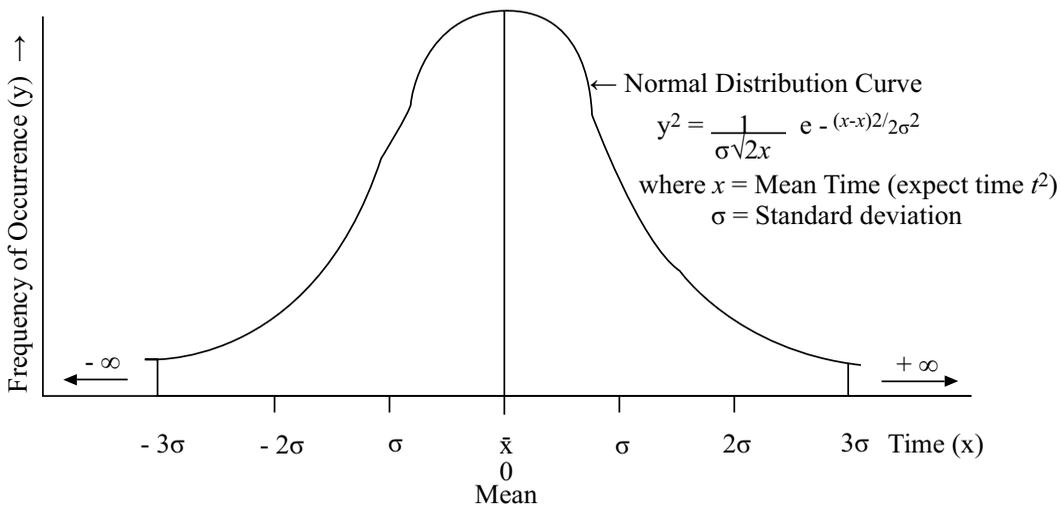
Statistics	Normal
Expected Value or mean	$(a+b)/2$
Variance σ^2	$(b-a)^2/36$
Standard Deviation, σ	$(b-a)/6$

P.2.5 Determining a probability distribution-fit for activity time duration

The method of fitting of a distribution based on a set of data is described in the standard books in statistics. Goodness-of-fit tests such as Ch-square can also be used for determining the distribution pattern. There are computer programmes available which can determine the density function. Reference may be to standard statistics book for determining the goodness-of-fit procedure for analysing an activity density data. The following steps provide a process for selecting probability distributions that best describe the uncertain variables in the spreadsheets:

Figure P.2

Statistics	Uniform
Expected Value or mean	a+(a-b)/2
Variance σ$_2$	(a^3-b^3)/[3*(b-a)]-(b-a)^2/4
Standard Deviation, σ	vv

Duration probability distribution

Area = 1

x

Figure P.3

Duration probability distribution

Area = 1

L   M   U

Time

Statistics	Uniform
Expected Value or mean	(b+m+a)/3
Variance σ^2	[(a^3-b)2+(m-a)* (b-m)]/8
Standard Deviation, σ	vv
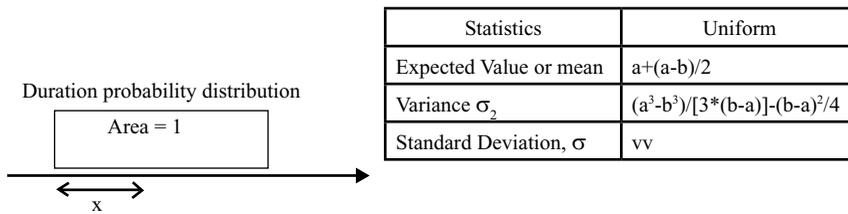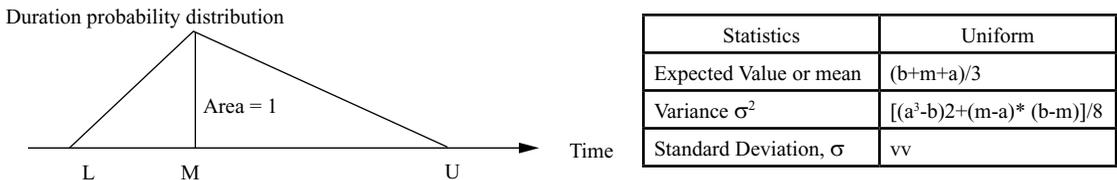
- Look at the variable in question. List everything you know about the conditions surrounding this variable.
- You might be able to gather valuable information about the uncertain variable from historical data.
- If historical data is not available, use your own judgment based on experience to list everything you know about the uncertain variable.
- As you review the descriptions, look for a distribution that features the conditions you have listed for this variable.
- Select the distribution that characterizes this variable. Each distribution type has its own set of parameters which are explained above.

Another method of selection of distribution-fit is to plot available data and select the distribution that nearly-fit the distribution mentioned above.

Note:

1. *Probability Density Function (PDF)*. Defines probability of the variables within an interval divided by size of interval.
2. *Cumulative Probability Function (CDF)*. Defines probability that a random variable is less than a given value.

Figure P.4
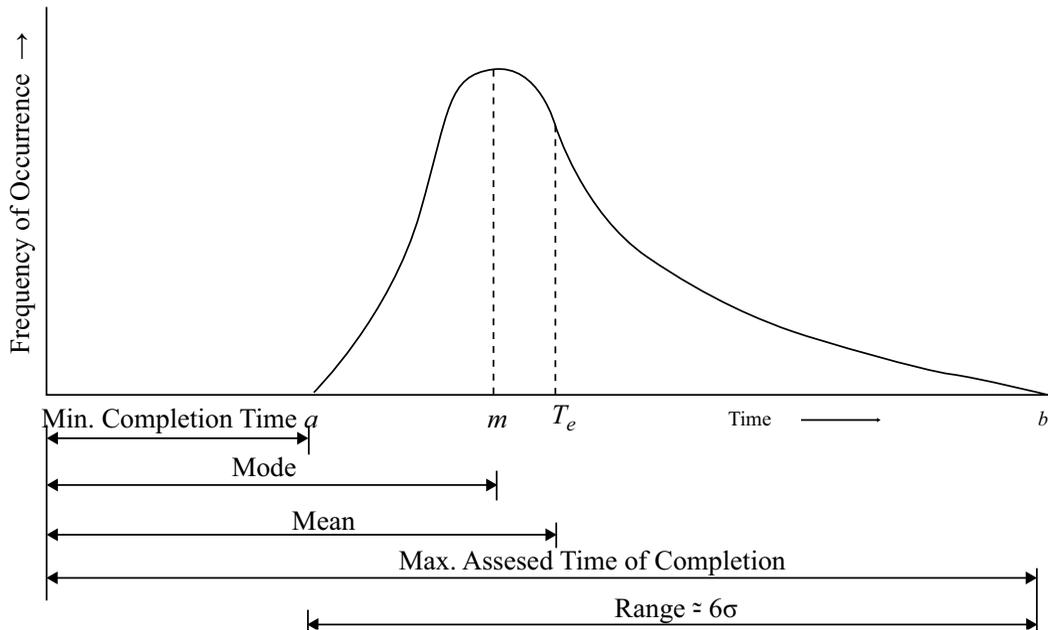
Statistics	Uniform
Expected Value or mean	$(a+4m-b)/6$
Variance σ^2	$(b-a)^2/36$
Standard Deviation, σ	$\dfrac{b-a}{6}$

❏ P.3 QUANTIFYING UNCERTAINTIES IN PROJECT DURATION ESTIMATION USING MONTE CARLO SIMULATION

P.3.1 Monte Carlo Simulation (MCS) Technique

A system such as project activities network is a collection of components that interact with each other and their environments. Simulation is an analytical method that is meant to imitate a real-life system, especially when other analyses are too mathematically complex or too difficult to reproduce. Simulation imitates the system output by randomly generating values for uncertain input variables within its probability distribution using appropriate simulation software like Crystal Ball. Monte Carlo Simulation can predict project completion time output with a defined confidence level by randomly generating values within its probability distribution input parameters using appropriate simulation software like Crystal Ball. Monte Carlo Simulations are used where each input data has continuous probability distribution function within the specified range. Generally it is based on basic probability distributions like normal, uniform and triangular distributions. The resulting

simulated output forecast quantifies the uncertainty in the system. The calculated uncertainty in the output is the probabilistic measure of the system model.

P.3.2   Crystal Ball Software Support

Crystal Ball is an analytical tool that enables the decision-makers to perform simulations on spreadsheet models. The spreadsheet model represents an actual or hypothetical system or set of relationships. Crystal Ball works with Excel spreadsheet models. Forecast is a statistical summary of the simulation results in a spreadsheet model, displayed graphically or numerically. The forecasts that result from these simulations help quantify areas of risk so that decision-makers can have as much information as possible to support decisions. Crystal Ball has wide applications. The tutorials in

Figure P.5

Crystal Ball Screen with Excel Add-in
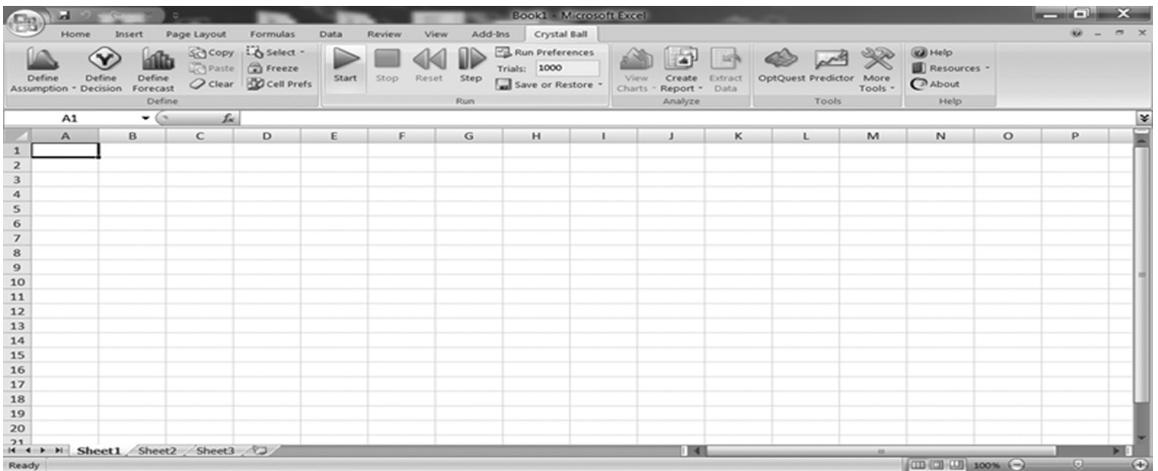
Crystal Ball (accessed on August 2013) include simulation solutions of Critical Path, Cost Estimation, Drill Bid Replacement, Return-on- investment and Real Estate Models Analysis. Crystal Ball screen has Excel Add-in as can be seen in **Figure P.5** below:

To help set up spreadsheet models and run simulations, Crystal Ball comes with a customized toolbar that provides instant access to the most commonly used menu commands.

The tools in the first three groups are from the Define menu. The tools from the next two groups are from the Run menu. The tools from the following two groups are from the Analyze menu, and the tool in the last group displays Crystal Ball online help. The key cells are outlined below:

a. Assumption cell—A value cell in a spreadsheet model that has been defined as a probability distribution.

Figure P.6

The Crystal Ball Toolbar
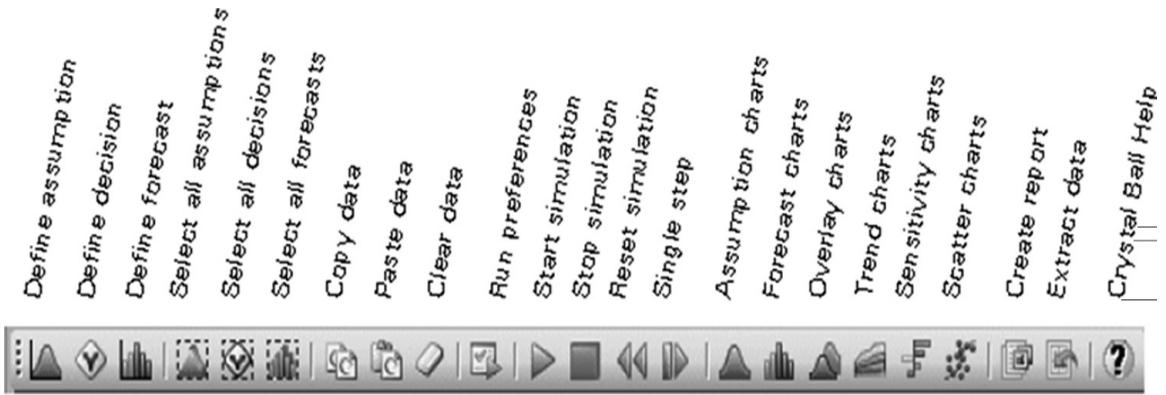
b. Forecast cell—Cells that contain formulas that refer to one or more assumption and decision variable cells and combine the values in the assumption, decision variable and other cells to calculate a result.

c. Decision variable cell—Cells that contain the values or variables that are within your control to change. The decision variable cells must contain simple numeric values not formulas or text.

P.3.3 Crystal Ball Software System Simulation Procedure

The Monte Carlo simulation for estimating probable project completion using Crystal Ball Software follows the procedure given here:

1. Inputs Identification

- Develop the network model. Time analyse the network to determine critical activities and project completion time.
- Define activities duration input assumptions with the probability distribution (uniform, triangular, normal, or other) for the duration of each activity. Generally, three-times triangular estimates is preferred. In the triangular distribution, it is easy to elicit three parameters (a, m, b). These three parameters can produce skewed, symmetrically skewed and fully skewed patterns.

2. Creating Excel Spreadsheet Model

- Create tabulated Excel spreadsheet as shown in examples 2 or 3 given in subsequent paragraphs.

- Incorporate defined assumptions for the duration of each activity in the network model. Note each column is linked with assumption variables.

3.   **Running Simulation**

- Generate random numbers by clicking on 'Run' and then 'Run Preferences' (generally 1000), using Crystal Ball software. A random number is a variable, which assumes different values conforming to the activity duration probability distribution, using relationship as depicted in the examples given in subsequent paragraphs.
- Run the above process on computer a number of times (say at least 1000 times) till the Runs are complete.

4.   **Analysing the output**

- Analyse the output data to determine project probability distribution, mean value, standard deviation, sensitivity and percentile. Each percentile represents the confidence level.
- The project probability distribution with its percentile data is then used to identify sensitivity of activities that will be critical to project completion. This enables estimation of the probability of completion of a project on a given date.

Monte Carlo can take duration of activities with varying probability distribution patterns. The network model generally uses triangular distribution to analyze the project schedule with the object of understanding how uncertainty affects the project completion. With the each simulated run, the model generates random numbers and performs time analysis, indicating the critical path, critical activities, mean duration and variance. After running a complete simulation (say 1000 runs), it evaluates the probability of each task on the critical path of the project and displays them in a histogram chart of the simulated values. Monte Carlo gives an unbiased estimate of the mean and variation of the project duration along with the degree of criticality of each activity. The analysed model can be used to focus on preventive measures to safeguard against delays and bottlenecks of these key drivers (critical tasks) to improve the outcome for the entire project, and minimising the project overruns. This information also enables forecasting probability of project completion in a given time schedule and to decide the acceptable risk level.

   The procedure for the application of Monte Carlo technique for time scheduling of a project is illustrated in subsequent examples of a simple network models using Crystal Ball Software. In practice over 1000 iterations generated on computers can give an unbiased estimate.

Example 1:   Illustrating fast-track completion time determination using Crystal Ball Step-by-Step. Consider a construction contract pre-tender stage, where the preparation of the tender involves the three concurrent activities having triangular distribution.

Step 1: *Input Identification by Developing Network and Defining Activities Input Assumptions*

Figure P.7

Contract-Pre-tender Stage Network

A-O-A Network   A-O-N Network
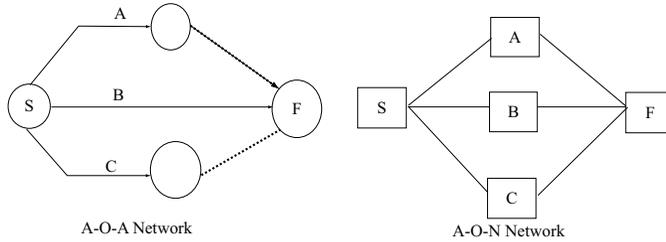
Define Activities Input Assumptions

Code	Activity Description	Assessed Three-Time Duration (days)
A	Preliminary design	50-55-65
B	Site investigation	50-60-75
C	Preparation of bid documents	45-50-70

Figure P.8

Defining Assumptions Cells and a Drop Down Menu of Analysis Charts
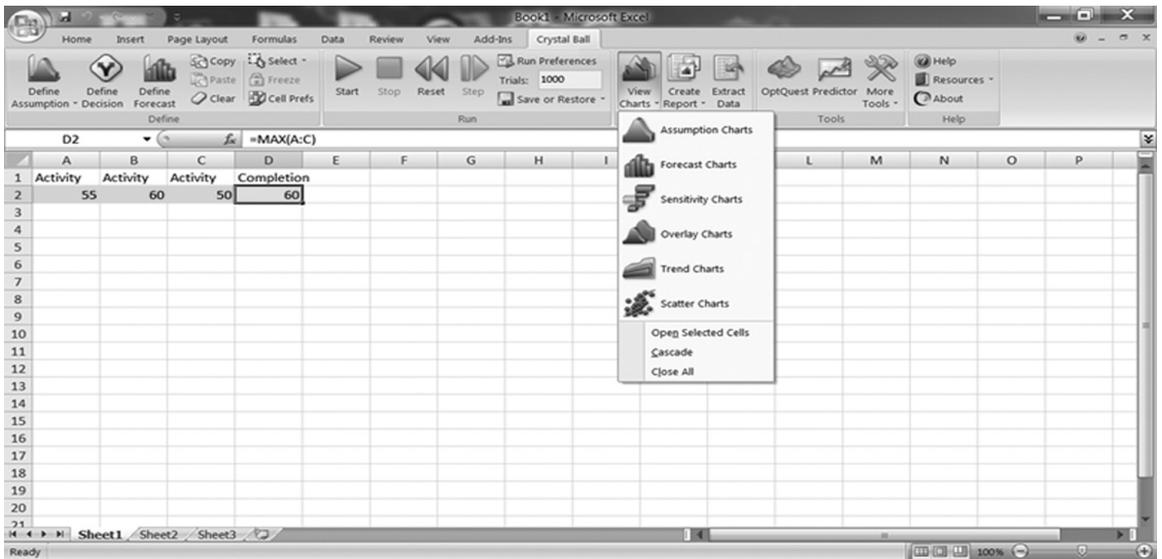
Step 2: Create Spreadsheet of Excel with Crystal Ball Aid-In. It is done by defining assumption cells, forecasting cells, decision variable and run preferences cells as appropriate. The **Figure P.8**

given below also shows a drop down menu of analysis charts available:

Step 3: Run Simulate System by Clicking on Run and Run Preference (1000 runs).

Printout after 1000 Runs

Statistics		A	B	C
Trials	1000	1000	1000	1000
Mean	63	56	61	55
Standard Deviation	4	3	5	5
Variance	19	9	26	28

Figure P.9

Statistics table, Probability Density Function, and, Cumulative Probability Function

Statistic	Forecast values
Trials	1,000
Base Case	60.00
Mean	62.97
Median	62.45
Standard Deviation	4.27
Variance	18.20
Skewness	0.2589
Kurtosis	2.62

Forecast: Completion

Percentile	Forecast values
0%	52.33
10%	57.61
20%	59.41
30%	60.57
40%	61.43
50%	62.43
60%	63.60
70%	65.25
80%	66.88
90%	68.85
100%	74.82
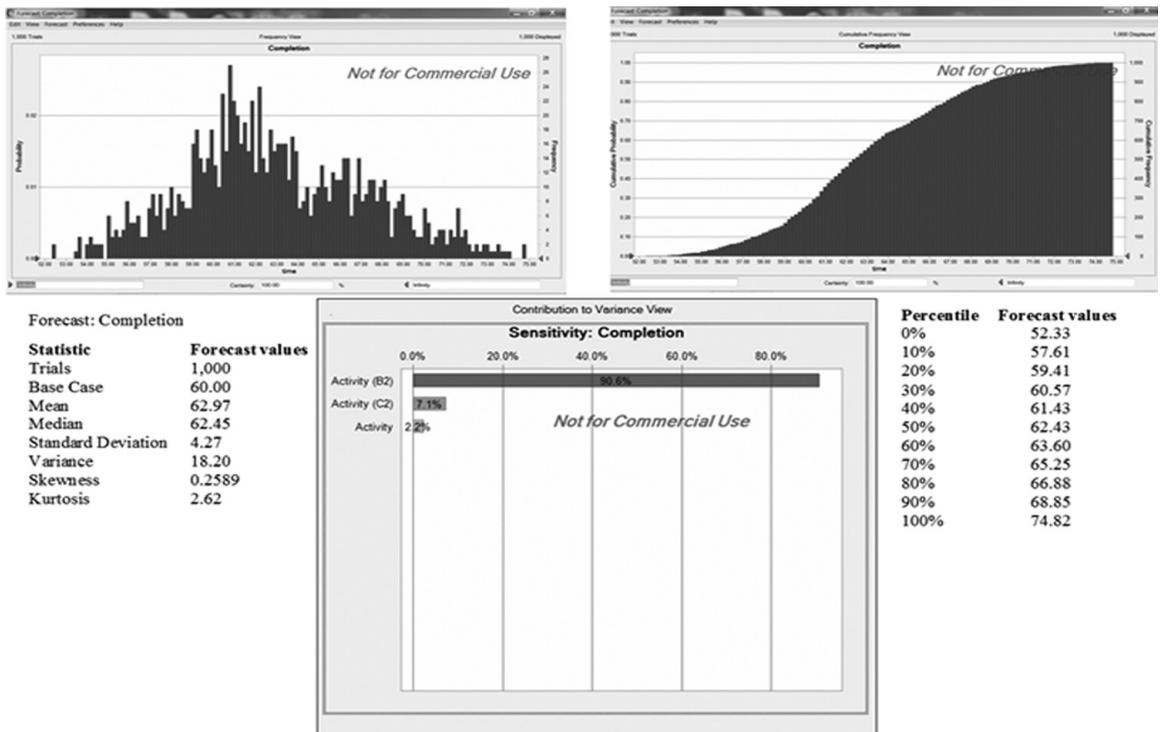
Step-4: Analyse Output Results. Statistics table, Probability Density Function, and Cumulative Probability Function given in **Figure P.9** below and reveals the project completion time.

Notes:

1. PERT analysis indicates that the Activity B is critical and the completion is expected in 61 days.

2. The above case, when simulated 1000 times with randomly selected inputs, shows the unbiased assessed mean completion period as 62.97 days. There can be marginal variation in output data to random nature of input data.

Example 2. Illustrates Crystal Ball Salient Features Step-by-Step

Step 1. Inputs Identification. Consider the Model Network given in **Figure P.10** with activities having three times durations estimates that follow triangular distribution pattern as tabulated here:
Steps 2–3. Create Excel-Crystal Ball Spread Sheet Model and Run Simulations

Figure P.10

Model Network
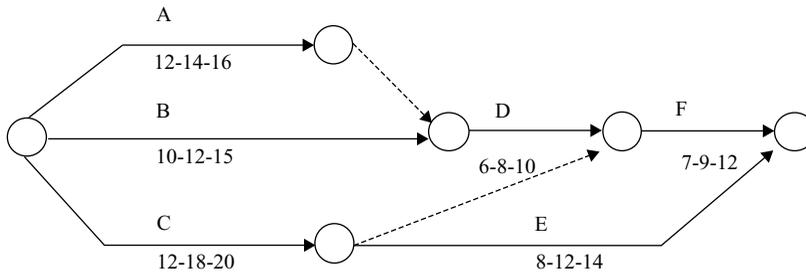
Activity-On-Arrow Network

Define Triangular Activity Input Assumptions as Tabulated below:

Activity	Precedence	Assessed Duration Minimum	Assessed Duration Most likely	Assessed Duration Maximum
Start		0	0	0
A	S	12	14	16
B	S	10	12	15
C	S	12	18	20
D	A, B	6	8	10
E	C	8	12	14
F	C, D	7	9	12
Finish	E, F	0	0	0
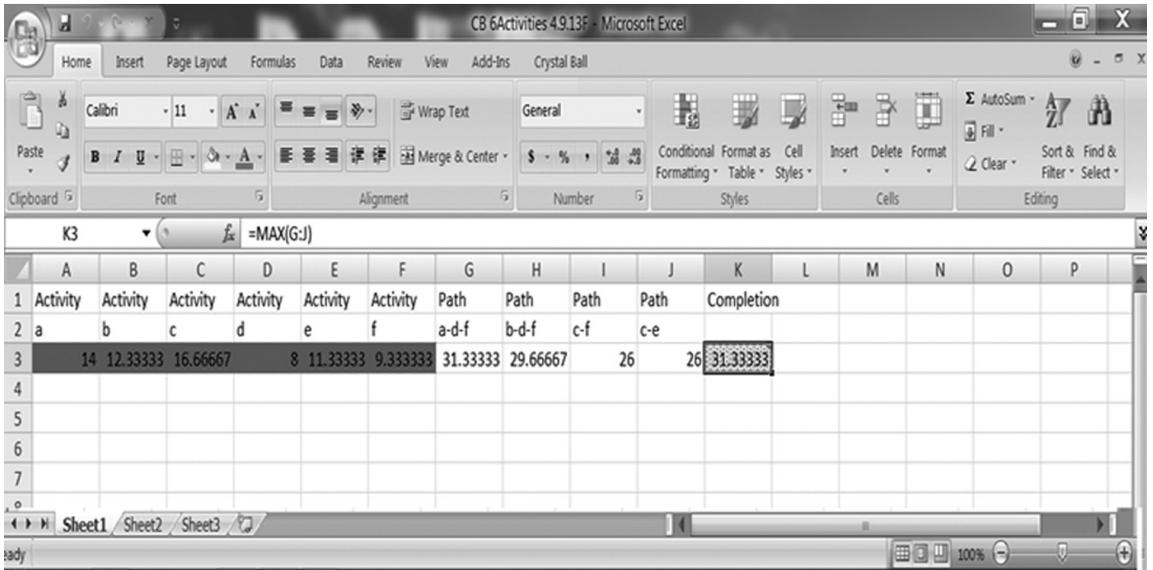
Steps 3–4. Simulate Spread Sheet Data and Critically Examine the Various Outputs (some given below) and Analyse Results.
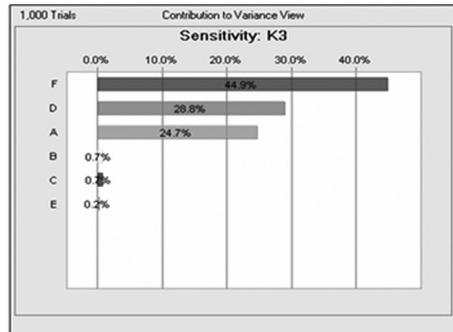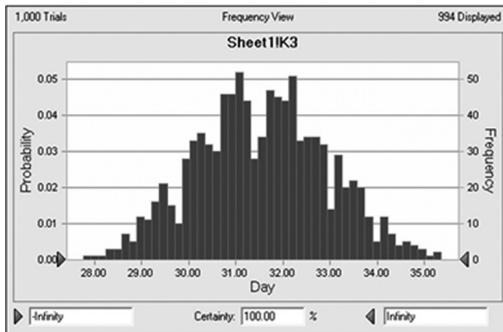
Forecast: K3	
Statistic	Forecast values
Trials	1,000
Mean	31.56
Median	31.57
Mode	'---
Standard Deviation	1.41
Variance	1.99
Skewness	0.0882
Kurtosis	2.81
Coeff. of Variability	0.0446
Minimum	27.27
Maximum	35.83
Mean Std. Error	0.04
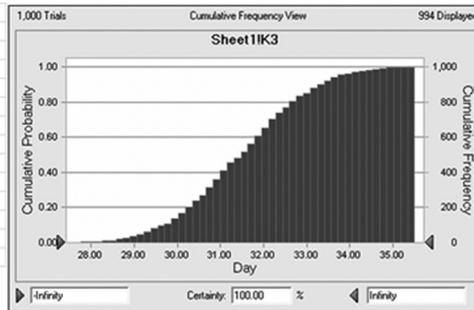
Forecast: K3	
Percentile	Forecast values
P0	27.27
P10	29.72
P20	30.33
P30	30.79
P40	31.13
P50	31.57
P60	31.94
P70	32.28
P80	32.75
P90	33.43
P100	35.83

Note 1: Crystal Ball has many Menu and drop-down boxes to provide variety of outputs as tabulated below.

Menu Commands	Drop-down breakups
Edit	Copy charts, Page set-up, Print view, Print
View	Frequency, Cumulative Frequency, Reverse Cumulative Frequency, Statistics etc.
Forecast Charts	Sensitivity, Fit Probability Distribution, Define Assumptions
Reports	Can be customized.

Note 2: As already mentioned, 1000 attritions are adequate to obtain an unbiased solution. Monte Carlo technique can simulate model understudy using large number of iterations, say over 1000 times, to determine a real life solution to analyse a network having varying activity, duration, probability distribution, and project completion time at given confidence level. There can be marginal variation in output data to random nature of input data.

Example 3. Sample Crystal Ball Tutorial.   The Network and Spreadsheet Model reproduced at the bottom, shows the sequencing of 20 Tasks of a project. This model using Crystal Ball, analyses as to how uncertainty affects project completion. The results of this model indicate which tasks should be addressed to improve the results for the entire project.
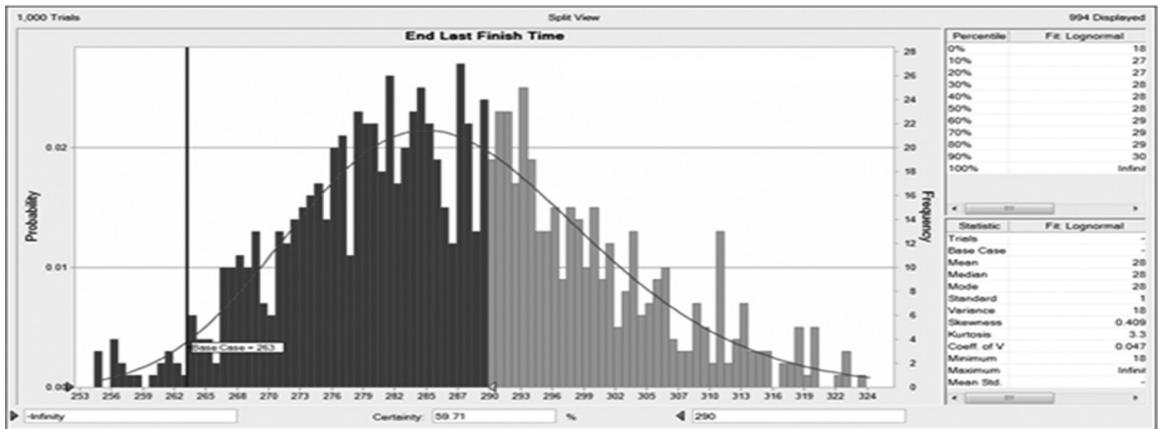
In the worksheet the task durations are in triangular assumptions. The precedence logic and sequencing are shown as to when subsequent tasks can begin. This model includes twenty probability distributions, referred to in Crystal Ball as 'assumptions.' These assumptions are the duration of each task. The duration in 'simulation column' is equal to the activity mode value (m). As in the network analysis, the formulas in the worksheet determine the earliest and latest starting and finishing times for each task, including the lag or lead entered in the spreadsheet for that particular step.

When the Crystal Ball simulation runs, the model performs a forward and backward pass, indicating in each trial whether or not a given task was on the critical path. After running a complete simulations (generally 1000 runs), the output shows the likelihood that any particular task is on the critical path of the project. The model also calculates the days of slack for each step, and formats the cells for those steps on the critical path (using conditional formatting). To view the details of an assumption, highlight the cell and either select Define Assumption from the Define menu or click on the Define Assumption button on the Crystal Ball toolbar. Notice that each assumption's name and parameters are defined by cell references rather than text or numeric values. This simulated model also includes 21 Crystal Ball forecasts. Forecasts are outputs, analyzed after a simulation. During a simulation, Crystal Ball saves the values in the forecast cells and displays them in forecast charts, which are histograms of the simulated values. In this example, the End Last Finish Time is at the bottom of the Column S (Cell highlighted in light blue).

This simulated model also includes 20 Crystal Ball forecasts. Forecasts are outputs, analyzed after a simulation. The Last Finish Time forecast is the main chart to examine the certainty of completion. After run of simulation, the forecast chart can be viewed to analyze the results such as statistics and percentiles. These are shown in Figures below:
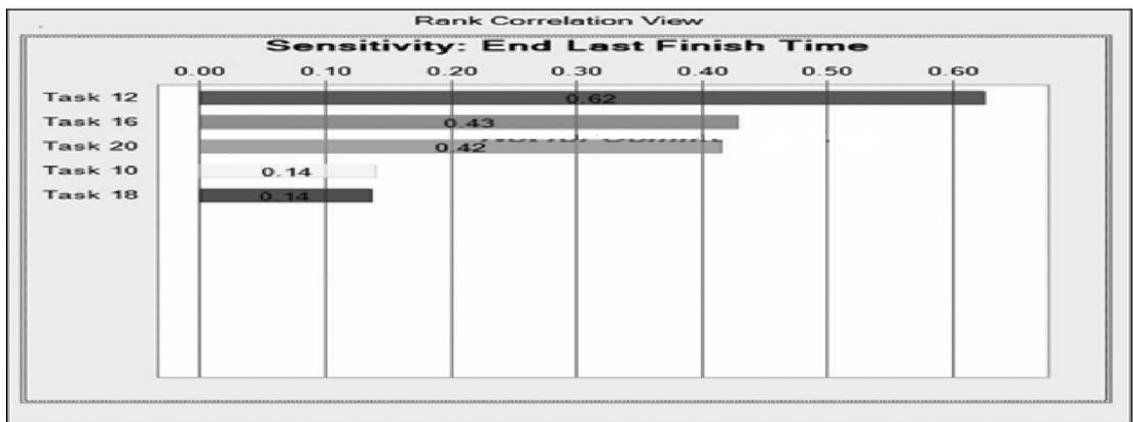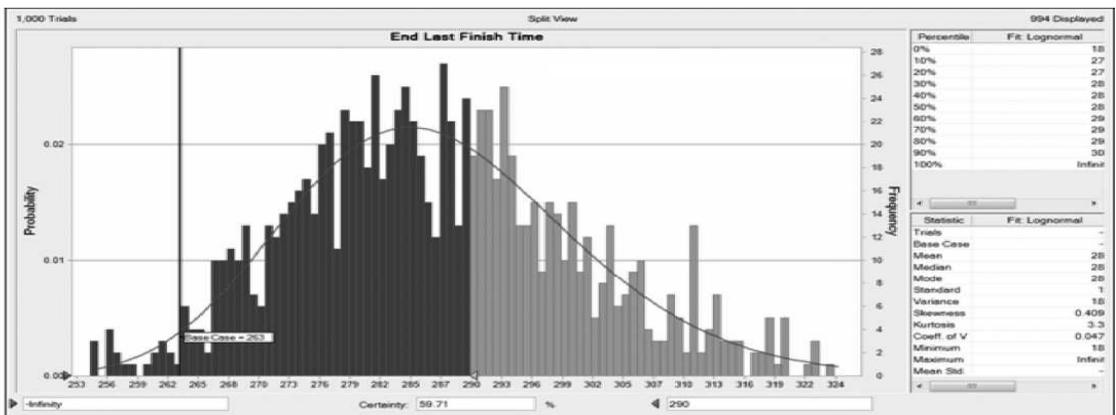
Risk Management at Construction Site—An Overview

In the early days of project management, projects were of short duration (about one to three years) and the environment was stable. The modern day projects, such as privatised infrastructure projects have a project life that is spread over many years. With globalisation of market, projects are becoming large in size and complex in nature. These projects involve large capital outlay, unbalanced cash flows, and complex contractual arrangements. They encounter changing economic and financial situations, face unstable political environment resulting in changing regulatory issues, and cater to unpredictable environmental changes. The stability of modern projects is thus, constantly subjected to certain sensitive and volatile environments, external as well as internal. The resulting instability causes uncertainty leading to elements of risk. The success or failure of a project largely depends upon the effectiveness and the efficiency with which the risks and uncertainties are managed. In fact, risk management has emerged as the main function of project management.

Project risk management is the art and science of managing risks that are caused by unforeseen changes (uncertainties), which may require deviations from the planned approach, affecting the achievement of the project's objectives. It involves systematically identifying, analysing, planning and controlling risks. Project Risk Management Model is shown in **Table 17.1**.

Risk analysis methodology vary with the project's maturity level and purpose of analysis, such as investment risk analysis, time overrun risk analysis, cost estimation risk analysis, toll revenue risk analysis, and construction safety risk analysis. The focus of this chapter is to outline the risk management structured approach for managing time and cost overrun risks during implementation phase of the construction project. It is divided into the following sections:

1. Risk Definition

Table 17.1

Project Risk Management Model

Processes	Tools and Techniques	Outcome
Risk Identification	Work breakdown analysis Brain storming Check-list templates Knowledge experts judgement	Sources of risks Potential risk events Project risks checklist
Risk Analysis	Risk qualitative approach for Risk Ranking Risk quantification for high value Risks	Risk Register Time-overrun Risk assessment Risk contingency assessment
Risk Response Planning	High exposure risks planning	Risk response plan/baseline
Risk Response Control	Monitoring risks	Risk-related corrective action Responsibilities allocation

2. Project Risk Management Strategy
3. Risks Identification
4. Risks Assessment Approach
5. Risk Quantitative Assessment Techniques
6. Risk Mitigation and Allocation
7. Project Risks Response Plan Development and Control Methodology
8. Multinational Corporation (MNC) Operations Risk
9. Performance Internal Audit Guidelines
10. The Human Side of Risk Management
11. Role of the Project Manager in Managing Risks
12. The Benefits of Managing Project Risk

This chapter assumes that readers are familiar with basics of knowledge areas of statistics and probability.

❑ 17.1   RISK DEFINITION

Risk is an abstract term. In a given situation, risk is viewed differently by different people. For example, the likelihood of rain on a cloudy day may be perceived as the risk of getting wet by a man walking in the street, a risk of slipping on the road by a motor cyclist, or an opportunity to plant the seeds by a farmer. To some it may pose a hazard, danger or threat, while for others it is an opportunity.

Project risk in general signifies the chances of occurrence of an uncertain event, situation, or condition, which may have an impact on project objectives, such as scope, time schedule, cost, and quality. It may have effect, either positively or negatively, on the project's objectives. Some risks may pose a threat to the achievement of project objectives, while some other risks may enhance achievement of objectives. Favourable risk events are called as opportunities, whereas, unfavorable risks are termed as threats. Factors that bring unfavourable risky situations are called as hazards. Risk increases with hazards but decreases with safeguards.

In the context of project, BS 6079-3:2000 defines risk as the, 'uncertainty inherent in plans and the possibility of something happening that can affect the prospects of achieving business or project goals'. PMBOK Guide defines risk as, 'an uncertain event or condition that, if it occurs, has a positive or negative effect on one or more of the project objectives'. In this chapter, risks having negative effect are considered. Methodology for positive effect risk analysis is similar. A risk has three components:

- An unforeseen situation leading to an event, the occurrence of which is likely to deviate from the estimated or forecast value or planned path;
- The probability of occurrence of that event. It is a number between '0' and '1'; and
- Likely impact of that event, i.e. loss or gain.

Risk exposure, is a function of the probability of occurrence and the consequences (amount of loss). Risk exposure is mathematically quantified by multiplying the probability of its occurrence with the occurred financial impact of the risk event.

$$\text{Risk exposure} = \text{Probability of occurrence of risk} \\ \times \text{Financial impact on occurrence of the risk event}$$

Notes:

1. If risk is affected by public perception, such as a fatal accident due to safety lapse resulting in a long duration strike by workers, then such risk can be defined as:

$$\text{Risk exposure} = \text{Probability of occurrence} \times \text{Consequences of impact} \\ \text{(including public perception)}$$

2. Risk impact is assessed at present monetary value.
3. Generally sources of risks are independent. They are mutually exclusive.
4. Some practitioners use negative sign to represent adverse exposures and positive sign to show opportunities.
5. Residual risk is the impact of risk that remains after risk response measures have implemented such as in workers safety measures.

Risk appetite is the degree of risk that an organisation or individual iswilling to take. or accept. Risk threshold refers to the level upto which an entity is prepared to accept the risk.

Some examples of evaluation of risk exposure are given in **Table 17.2**.

$$\overline{\text{Table 17.2}}$$

Example of Risk Exposure

Risk Event	Probability of Occurrence	Impact if Risk Event Occurs	Risk Exposure
Failure to complete project on time	40% chances of 2 weeks delay	Penalty Rs. 200,000 per week	0.4 × 2 × Rs. 200,000 = Rs. 160,000
New state government may change the regulatory policy	20%	Redesigning may cost Rs. 100,000	0.2 × Rs. 100,000 = Rs. 20,000
Material supply from present local vendor may fail	40%	Additional expenses Rs. 100,000	0.4 × Rs. 100,000 = Rs. 40,000.

❑ 17.2   PROJECT RISK MANAGEMENT STRATEGY DEVELOPMENT

17.2.1   Factors Affecting Risk Management

The factors in the following **Table 17.3** indicate the extent of risk, which is encountered during construction phase of the project:

17.2.2   Need for Project Risk Management Plan

Risk management is at the core of all business at organisational and individual activities, regardless of their nature or size. In a project, all stakeholders (owner, sponsor, consultants, designers, project manager, and others) face risky situations. All of these stakeholders aim to minimise adverse risks and enhance risky opportunities. For example:

1. A client may resort to a lump-sum type of contract to overcome resource fluctuations, cost inflation, and quantity variation risks. The client may also opt for a turnkey contract approach to prevent design risks and incorporate penalty clauses in the contract to compensate for damages resulting from time delay risks.
2. Similarly, a contractor may enter into back-to-back agreements with his sub-contractor and suppliers and incorporate suitable escalations along with safeguards as part of the subcontract agreement.

Despite the various strategies that stakeholders adopt in order to avoid risks, the fact remains that risks are unavoidable. Risks vary from project to project and with the role of the stakeholders. Project stakeholders cannot stop the fast-changing, unstable, risk-prone environment, however, they must prepare themselves to manage the impact of risks to their role in the project. All stakeholders

Table 17.3

Factors Determining Risk Impact during Construction Phase

Factors	Low Risk Impact	Higher Risk Impact
Percent of contract completed	0% –25%, and after 90% completion	25%–90%
Size of project	Relatively small job	Relatively large job
Type of project	Simple/ routine Within contractor's expertise	Complex Not within contractor's expertise
Timing and scheduling	Short-term project Work is on schedule Comfortable time frame No penalties for late completion	Long-term project Work is falling behind schedule Accelerated time frame Significant penalties for late completion
Location	Familiar area, with past successful projects—Materials and labour readily available	New area or remote areas—materials and labour not readily available
Weather	Low susceptibility to adverse weather	High susceptibility to adverse weather
Owner/investor	Solid financial position	Weak financial position
Subcontractors	Large portion of work performed by subcontractors Many previous contracts with contractors Strong financial position Majority of significant subcontract agreements finalized	Small portion of work performed by subcontractors Very few previous contracts with contractors Weak financial position Majority of significant subcontract agreements not finalized
Bid Spread	Narrow variances in bid amounts among competing contractors	Significant variances in bid amounts among competing contractors
Profit Margin	Reasonable	Significant
Type of contract	Item rate -type, clear definition of reimbursable costs	Fixed-price Cost-type, difficult to determine reimbursable costs
Claims	No claims	Significant claims
Material costs	Low susceptibility to price escalations during performance of contract	High susceptibility to price escalations during performance of contract

should prepare contingency plans to handle risks. If the project risks can be identified well in time, quantified in a logical manner, allocated among the stakeholders and managed effectively; then the likelihood of schedule and cost overruns is significantly reduced.

The risk management responsibility can be assigned to appropriate stakeholders and functional heads, and can be coordinated and monitored by the project risk management team. For example, the risk responsibility and liabilities between a client and a contractor is generally demarcated in

the conditions of contract, e.g. Clause 20.4 of FIDIC (1992 edition) defines employer's risk responsibility and Clauses 21–25 stipulate the contractor's risk and liabilities. In both cases, it makes provisions for mitigation of these risks through insurance, which is only a part of risk management. Project risk management plan involves identifying, analysing, mitigating, planning, and controlling risks, which might affect the performance of the project. This chapter outlines these processes and the related techniques for managing risks.

17.2.3   Project Risk Management Plan Key Contents

The project risk management plan prepared by both, client and contractor, (separately or jointly will depend upon the terms of the contract), prior to commencement of the construction phase outlines the policy for managing project risks. This plan should state, nature of risks and how they will be managed.

There is no tailor-made approach for developing risk management plan to combat risks and pinpoint responsibilities. But the instability in a risk-prone environment results in structured approach for managing risks to achieve the specified performance objectives of a project. Risk project management plan should include at least one of the following:

a. *Risk management methodology*. It should define the approaches, tools, and data sources that may be used to perform risk management on the project.
b. Roles and responsibilities of each member involved in the risk management plan.
c. *Risk sources and events*. It should provide a structure that ensures a comprehensive process of systematically identifying risks that can lead to the preparation of the Risk Breakdown Structure (RBS).
d. *Risk budget*. It should indicate the physical and monetary resources that are earmarked for risk management, inclusion in the cost performance baseline, and establishing responsibilities for applying contingency and management reserves.
e. *Risk register*. It defines the format of the risk register as well as the course of actions for management of the identified risks.
f. *Project tolerances*. It should indicate that the project baseline tolerances are acceptable to project stakeholders.
g. *Monitoring frequency, reporting formats and communication*. It should define how the outcomes of the risk management processes shall be documented, analysed, and communicated.

17.2.4   Project Risk Management Team: Role and Responsibilities

The role of the project risk management team should be to minimise uncertainties and move towards opportunities and manage project risks proactively, efficiently, and effectively . It involves risk identification, assessment, response planning, monitoring and control, and documentation of

lessons learnt. These processes, tools, and techniques of project risk management during the construction phase are briefly covered in the subsequent sections of this chapter.

Depending upon the size, nature and complexity of the project, risk management team comprises of the project execution team and selected project stakeholders. The risk management team develops and manages the risks involved in a project. The tasks assigned to the risk management team may include but not limited to the following:

1. What are the nature of risks that are likely to be encountered in the project?
2. What is the probability of occurrence of these identified risks?
3. What is the likely impact on the project in terms of time, resources, cost and change in its scope?
4. What are the possible responses and their cost to the project?
5. Will any of these responses lead to other risks?
6. How to reduce or eliminate or mitigate the risk consequences, if they occur?
7. What should be the options with the management to deal with the risks?

The role, accountability, and reporting structure of the project risk management team should be well defined and documented.

A risk management plan, developed well in advance, can minimise the consequences of possible adverse future events. It makes the project plan realistic, reduces costly surprises, minimises losses and delays, and enables exploitation of beneficial opportunities.

❑ 17.3   RISKS IDENTIFICATION

17.3.1   Risk Identification Approach

It is said that the real risks in project management are the ones which we fail to identify. According to Murphy's Law, if something can go wrong it will, and if, something cannot go wrong it still will. This law implies that even if things tend to go wrong when least expected, it is still possible to respond quickly provided prior 'thinking' has been done. The identification process, therefore, must aim at exploring all possibilities to locate the risk source and risk events, thereby, reducing the chances of overlooking any potential risk. The risk identification process involves, analysing the project to determine sources of risks and connected potential risk events. It may be noted that risk identification is an ongoing process throughout the project as opposed to one time exercise because the condition may change with passage of time.

17.3.2   Sources of Risks

Modern projects, encounter unlimited risks from inception to the closure stages. Commonly encountered risk sources are, commercial risks, design risks, natural disaster risks, cost overrun risks,

and time overrun risks. Sources of risks are generally independent of each other. Most of the project predicted risk sources can be planned proactively in advance for remedial measures and are listed in the Risk Register for response development, while the unknown uncertainties are mitigated separately as they cannot be proactively planned.

Project Risk Sources

External Environments Predictable Sources	Internal Environments		External Environments Unknown Uncertainties
• Political and Regulatory • Design and Specifications • Financial and Economic	• Scope Changes, Time Overrun and Cost Overrun • Technology Change • Quality and Specifications Failures	• Leadership and Organisationa Failures • Resource Failures • Contractor Failures	• Acts of God • Ecological • Safety and Health

Most of these sources of risks arise from changes taking place in the environment (external and internal):

1. Changes in the external environment, which can be caused by unstable political, regulatory, economic and financial conditions, or natural disasters, such as fire and floods. External risks can be further divided into external unpredictable risks (unknown uncertainties) and external predictable risks (known risks).
2. Changes in the internal environment at the project site takes into account technology changes, quality considerations, legal problems, commercial dealings, internal safety, security of resources, accidents, errors in estimation, design alterations, labour strikes, materials wastage, equipment breakdown, project management internal conflicts, client-contractor disputes, corruption, and man-made catastrophes like burglary and fraud. These internal environment changes can be broadly divided into risks relating to project management objectives and project management practices.

The sources of risk in a typical building construction complex project can be classified as reflected in **Figure 17.1**.

Risk sources (also called risk factors) may be limited around 15 to 20. Once a risk source is established, it can be suitably priced and a system can be developed to cope with it. Further, the corporate office generally handles external risks as these affect the project's objectives and its direction. Internal risk management falls within the preview of the project management.

17.3.3　Risk Events

Sources of risk (also called as risk factors) are divided into risk events. Most risk events can be identified by breaking down the risk sources into manageable level of details, by project

Figure 17.1

Project Risks Breakdown Structure of a Typical Construction Project

Project Risk

Internal Environments

External Environments
Predictable sources

- Political, WTO & Legal
- Design & Specifications
- Financial & Economic

External Environments
Unknown Uncertainities

- Act of GOD, Force Majeure
- Ecological
- Safety & Health

Leadership & Organisation Failure

- Communication Failure
- Resources failure
- Contractor Failures
- Quality Failures

- Scope Changes
- Time Overrun
- Cost Overrun
- Technology Changes

objectives, work packages, management functions, brain storming, judgement based on the knowledge experts, or a combination of these. This breakdown enables the risk planners to recognise the nature of risk events likely to be encountered.

There are numerous methods for identifying risk events. Some of the commonly used methods are outlined below:

Project risk sources interaction matrix   Project risk sources and project objectives interaction matrix. Typical project specific partial risks and objective implication matrix, outlined in **Table 17.4**, can be developed in detail. To quote example leadership functions related risks are outlined in **Table 17.5**.

Table 17.4

Risk Sources-Project Objectives Risks Interaction Matrix

Risk sources	Scope	Time	Cost	Quality	Finance	Org.
Internal environments						
Scope changes	X	X	X			
Technology change	X					
Leadership and Organisational failures						X
Resource failures	X	X	X			
Contractor failures						X
Quality failures				X		
External environments predictable sources						
Political and Legal changes					X	
Design and Specifications failures	X	X	X			
Financial and Economic failures			X		X	
External environments unknown uncertainties						
Acts of God Damage	X	X	X		X	
Ecological failures			X			
Safety and Health failures		X	X			X

Other Risk Identification Approaches

- *Planning assumptions and constraints accuracy*. It involves raising questions, such as what is the accuracy of each assumption and constraints and in case if some of them are not realistic, will they affect the planned objectives.
- *Performance analysis of past projects*. Information relevant to risk in a project under consideration can be obtained from lessons learnt in similar past projects.
- *Brain storming*. It is a creative data gathering technique where all the participants are allowed to contribute in the discussion.

Table 17.5

Leadership Functions Related Risks and Possible Safeguards

Leadership Risk Factors	Impact				Possible contingency plan
	Cost	Schedule	Quality	Org.	
High turnover of critical team members	✓	✓	✓	✓	Support with back-up team members
Lack of senior management support	✓	✓	✓	✓	Conduct regular management review meetings
Poor communications					Hold frequent meetings
	✓	✓	✓	✓	Distribute documentation
Poor motivation of participants					Encourage greater participation in the decision-making process
	✓	✓	✓	✓	Assign responsibility for complete units of work

- *Use of check-list templates*. See Building Project Risk Check List Template given in **Section 17.3.4**.

17.3.4 Risks Check-list of a Building Project

The risk factors and risk events are consolidated to form the risks checklist. The check-list will vary from project to project and agency to agency. A typical check-list showing risk events are categorised under risk sources, which may be encountered in a turnkey construction contract, is given below. The list is indicative but not limited to the following:

1. **Project scope risks**. High complexity, ill-defined project scope, frequently changing scope requirements, no project charter, no delegation of authority, ineffective control systems, no extra-work control, no analysis of changes, and problems in quality control.
2. **Design and specifications risks**. Inadequate design information, incorporation of new construction technology, unrealistic specifications, likelihood of design changes, difficulties in interaction of design with method of construction, non-standardisation of resources, designers, delays, poor design and shop drawings, and non-conformity with national and local specifications.
3. **Quality risks**. No quality assurance plan, no soil investigation, no method statements, poor quality materials, untrained manpower, absence of approved soil and material testing laboratories, unachievable quality specifications, problems in quality control, and re-working of defects during construction.
4. **Time overrun risks**. Inaccurate activity time estimates, unrealistic time schedules, in-complete work breakdown structures, no formal sequencing plan, poor allocation of resources,

incomplete assessment of project time, cost, resources, and quality implementation plans, no database, ineffective control system, inflexible and unrealistic project plans, unsatisfactory conduct of status review meetings, and inability to take timely corrective action.

5. **Cost overrun risks**. Inaccurate cost estimates, inadequate cost planning and control, no extra work control, no analysis of constantly changing market conditions, and incomplete project closure.

6. **Leadership risks**. No project vision, no team building, poor motivation of participants, high turnover of critical team members, indecisiveness, unreasonable stakeholders expectations, lack of senior management support, lack of team consensus over project plans, limited authority/control of the project manager, poor communications, poor industrial relations, high rate of sickness and absenteeism, unsafe working conditions resulting in accidents and poor turnover, conflicts among staff and participating organisations, lack of co-ordination, insufficient liaison with public services, and barriers in information communication.

7. **Organisational risks**. Inappropriate organisation network, poor assignment/allocation of tasks and responsibilities, lack of competent persons, no project manual/documented procedures/processes, project being too complex for the resources available, inadequate communications infrastructure, wrong selection of project management, no database, inflexible and unrealistic project plans, poor quality control, unsatisfactory conduct of status review meetings, inability to take timely corrective action, and incomplete project closure.

8. **Physical resources mobilisation and utilisation risks**. Inadequate and low quality procurement of resources, non-availability of spare parts, special equipments and materials; transshipment delays, low productivity, bad weather and working conditions, non-availability of' suitable sub-contractors, damage during construction due to negligence, transportation or storage vandalism, accidents, wastage, theft and fraud, lack of safety and hygiene measures, and local requirements.

9. **Technology risks**. Inadequate information on new technology, non-replacement of old technology, non-availability of competent and professional staff to use new technology, and lack of managerial skills.

10. **Contractual risks**. Non-standard and inconsistent conditions of contract, insufficient time to prepare bid tenders, delay in site possession , errors or omissions in bills of quantities, payment problems, extra work variations, unrealistic tendered amount, no-credit worthiness of contractor, high cost of legal decisions, insufficient insurance and surety, incorrect documentation of claims and disputes, and un-familiarity with local laws.

11. **Force majeure and ecological risks**. God's judgements on nature—due to mankind's rebellion against God—such as earthquakes, floods, landslides, ecological disaster, epidemics, etc.

12. **Political, regulatory and social risks**. Changes in government, policies, regulations, rules, laws, war, revolution, civil disorder, risks under criminal law and the law of tort, pollution, waste treatment, local regulations, constraints on the availability of labour, import-export restrictions and procedures, joint venture rules, inconsistency of regulations within the coun-

try, requirements for licenses and permits, crime and insecurity, bribes and corruption, and religious and cultural conflicts. WTO risks include foreign exchange fluctuation, interest rate changes, country specific political and economic stability risks, and delays in arrival of imported materials and equipment.

13. **Financial and economic risks**. Investment risk, inflation, escalation of prices, availability and exchange rate fluctuations, local and national taxes, inadequate sources and availability of funds, cash flow problems, effect of time and cost overruns, default of stakeholders and suppliers, demand scenario, and constantly changing market conditions.

14. **Safety, health, and environment risks**. Unsafe working conditions, non-conformance to statutory requirements for workers safety, healthcare, environment protection, absence of safety audits, accidents/strikes/work stoppage and workers' perceptions, inadequate healthcare, security, fire-fighting, and disaster management capabilities.

15. **Funding failure risks**. Lenders not comfortable with project viability, failure to arrange partners equity in time, high interest rate, adverse investment climate, revenue short falls (BOT) projects, debt servicing risks, partners conflict, non-availability of finance from lending institutions in time.

16. **Communication and network failure risks**. Non-availability of antivirus software to safeguard office computers, loss of data due to network breakdown, no back up of data available, vendors not competent enough, landline phones not working properly, lack of resources, high electricity fluctuations, internet servers breakdown, installation of wrong computer equipment, non-compatibility of software with the purchased hardware, and ineffective information management system.

Note: BOT projects, e.g. an express-highway project encounters many additional complicated risks like; Partnering risk; Financial risk; Environmental risk; Regulatory risk; Delay in land acquisition, tree-cutting, and utility shifting; Delay in financial closure; Technology and Design risks; Completion time and Cost overrun risk; Demand and traffic revenue risk; Operation risk; Debt servicing risk; Regulatory risk; and Political interference risks.

❑ 17.4 RISKS ASSESSMENT APPROACH

17.4.1 Nature of Risk Assessment Approaches

Risk assessment involves overall ranking of risks using t and quantifying the risk exposures for mitigating high-exposure risks for developing risk response plan.

17.4.2 Risk Qualitative Assessment Approach

The risk qualitative assessment approach focuses on segregating risk events into high, moderate and low exposure categories. There are numerous techniques for Qualitative Risk Analysis, such as

Root cause analysis, Documentation review, and Probability-impact matrix. However, commonly used technique is the Probability Impact matrix.

Probability-Impact Matrix.   This can be done by developing a simple probability and impact matrix for each risk event. The four main categories of risk exposure in this simplified approach are:

Cost impact	Occurrence Probability	Exposure Category
High	High	High ImpactxHigh Probability (HH)
Low	High	Low ImpactxHigh Probability (LH)
High	Low	High ImpactxLow Probability (HL)
Low	Low	Low ImpactxLow Probability (LL)

The risk exposure can be positive or negative. In addition, some of the low probability and low cost risks may carry a marginal cost impact.

Another practical method is to rank the risk exposure by assessing the subjective probability of each risk event (say below 10% for low probability, 11%–30% for medium probability and above 31% for high probability) and defining the range of monetary value for each type of impact either as a percentage of profit or within a specified range (say within Rs. 100 000 for low value, Rs. 100 000 to Rs. 500 000 for medium value and above this for high value). This will generate a nine cell matrix classifying exposure into HH, HM, HL, MH, MM, ML, LH, LM, and LL categories (see **Table 17.6**). Then risk exposures can be ranked in descending order ABC analysis or applying the Pareto's 80/20 rule for selecting major risk events requiring further analysis.

Table 17.6

Typical Risk-Impact Grid to Determine Severity of Risk of a Medium Size Project

Impact consequences	Severity of Risk Probability		
	Low probability (below 10%=)	**Medium probability (11%–50%)**	**High probability (51% & above)**
Low value (within Rs. 100 000)	Low probability low impact	Medium probability low impact	High probabilitylow impact
Medium value (Rs. 100 000 to Rs. 500 000)	Low probability medium impact	Medium probability medium impact	High probabilityme-dium impact
High value (above Rs. 500 000)	Low probability high impact	Medium probability high impact	High probability high impact

Note: The above probability measures are subjective.

Qualitative Risk Analysis Outcome.   Overall Probability Impact matrix using qualitative analysis approach enables:

- Identification of risk events/sources having high, medium, and low value exposures that can be considered for ranking;
- Sorting of high exposure risks that can be considered for quantification and mitigation using Pareto's rule;
- Prioritisations of risks for inclusion in risk register; and
- Segregation of low exposure events (non-critical) for placing in the watch list. Those ranked in the low exposure group may not require proactive action as compared with those falling in medium and high exposure zones.

To quote example, the aspects considered in developing a Probability Impact Matrix prior to bidding for a tender by a MNC are tabulated in **Table 17.7**.

Table 17.7

Typical Probability-Impact Evaluation Format of a MNC

Risk Item	Risk Rating		Mitigation Measures
	Severity	Probability	
I. Geopolitical			
A. Government Instability	Low	Low	
B. Economic Downturn	Low	Low	
C. Expropriation[1]	Low	Low	
D. War/ Terrorism	Low	Low	
E. Natural Disaster	Low	Low	
F. Change-in-Law	Low	Low	
G. Banking Restrictions	Low	Low	
II. Commercial			
A. Competition	High	High	
B. Client Credit	Low	Low	
C. Revenue Protection	Low	Low	
D. Cost Escalation/ Inflation	Low	Low	
E. F/X Fluctuations	Med	Med	
F. Debt Repayment Guarantee	Low	Low	

G. Power Availability	Low	Low
H. Termination	Low	Low
III. Technical		
A. Battery Limits Undefined		
B. Health and Safety	Low	Low
C. Environmental	Low	Low
D. Technology/ Process Risk[1]	Low	Low
IV. Construction		
A. Cost Overruns	Low	Low
B. Delays	Low	Low
C. Performance Shortfall	Low	Low
D. Capacity Shortfall	Low	Low
E. Natural Disaster	Low	Low
F. Political Unrest	Low	Low
V. Operations		
A. Cost Overruns	Low	Low
B. Power Interruption	Med	Med
C. Performance Shortfall	Low	Low
D. Capacity Shortfall	Low	Low
E. Natural Disaster	Low	Low
F. Political Unrest	Low	Low

Risk Register.   The primary output from qualitative assessment is to rank the risk into high, moderate, and low exposure categories. These are then listed in risk register in order of severity of project risks as high and low (or A, B, C) categories. The high exposure risk events are identified using Pareto's 80/20 Rule (implying that 80% of the risk events account for 20% of the risk exposure and 20% of risk events contribute to 80% of risk exposure). It can be used to categories and rank the risks. The 20% high probability-high impact risk factors need to be further examined in detail, for estimation of the project risk exposure and preparation of the risk response plan. Generally, about 15%–30% potentially high exposure risk sources can be targeted for risk quantification. Low category risks are put in the risk register on the watch-list of low priority risks.

17.4.3   Risk Quantification Approaches

Quantification assessment is done for potentially high exposure items, which are ranked after the risk qualitative assessment process is completed. If several hundred risk events are used for

quantitative analysis, then the analyser will get lost in minor tactical risk events and may overlook critical risks. The techniques of risk quantification will depend upon the nature of the risk under consideration. There are various techniques that may be used for quantitative risk analysis. Some of these are given below, These are beiefly rescribed in subsequent paragraphs:

- Decision tree analysis,
- Expected monetary value (EMV),
- Monte Carlo Simulation, System dynamics, and
- Sensitivity analysis.
- Time and cost over runs.

Risk response strategy needs to be integrated with the overall project management plan to assess probability of its effective implementation, its efficacy in mitigating risks, expected post-response scenario, and expected requirement of additional response strategies or fall back plan.

Risk is mathematically quantified by multiplying consequences with the probability of its occurrence.

Risk exposure = Probability of occurrence of risk × Impact of the event

In order to quantify a risk, it is necessary to determine the probability of risk occurrence. The probability of risk occurrence of a can be of two types, i.e. objective probability and subjective probability.

Objective probabilities.   This is based on the observed relative frequencies of past incidences of an event, e.g. lessons learnt from past occurrences and past performance data. This technique applies to identical repeatable events.

Generally, the certainty in a risk factor having high potential for variability can be assessed by treating variability as random variables. For example, instead of a deterministic approach in the estimation of an activity duration or unit rate for an item of work, these can be modeled as variables. The known matching statistical distribution can be used to conduct a probabilistic analysis for determining the project mean and standard deviation.

The main features of the selected distribution must be that it should have confined limits (range) with positive values, should be unit-model, and may be skewed (un-systematical). Such distributions include Beta distribution (as defined by PERT statisticians), Uniform distribution, Triangular distribution, Rectangular distribution, Lognormal distribution, and Normal distribution. Formulae for estimation of approximate mean and standard deviations of these activity probability distributions are given in **Table 17.8**.

The above Probability Distributions formulas given in **Table 17.8** are approximations only and can be used for practical purposes. Readers may refer to standard books on statistics to understand these probability distributions and calculate their theoretical mean, variance and standard deviations.

Table 17.8

Probability Distributions Approximates Statistics for Simplifying Calculations

Statistics	Normal	Beta	Triangular	Uniform
Expected Value or mean	$(a + b)/2$	$(a + 4m - b)/6$	$(b + m + a)/3$	$a + (b - a)/2$
Variance $v = \sigma^2$	$(b - a)^2/36$	$(b - a)^2/36$	$[(b - a)^2 + (m - a) *$ $(b - m)]/18$	$(b^3 - a^3)/[3\mathrm{x}(b - a)]$ $- (b - a)^2/4$
Standard Deviation, σ	$(b - a)/6$	$(b - a)/6$	$\sqrt{v}$	$\sqrt{v}$

Note: a = Optimistic value, b = Pessimistic value, m = Most likely value, v = Variance

Thereafter, with the application of the central limit theorem, the mean and variance of the system can be calculated as:

$$\text{Mean}, x = x_a + x_b + x_c + \ldots + x_n$$
$$\text{Variance}, V = V_a + V_b + V_c + \ldots + Vn$$
$$\text{Standard Deviation}, \sigma = \sqrt{V}$$

Objective probabilities determination method is unsuitable for most of the real world problems in construction project management.

Subjective probabilities.   This is based on opinions and judgements of experts about the occurrence of a risk event. In a subjective risk assessment the uncertainty of an event is perceived by an individual observer, who is influenced by his attitude, preferences, experiences and the relevant/relative information available.

Generally, in real life situations faced in projects, the subjective method of probability assessment is used. The two commonly used expert judgement techniques are Delphi Method and Nominal Group Technique. In the Delphi Method, the identity of experts is not revealed to each other and they do not interact face-to-face. In the nominal group technique experts meet to discuss their opinions.

The Delphi method adopts the following procedure:

- Select a panel of experts from inside and outside the organisation;
- Ask experts to make a prediction on the subject under study;
- Compile their replies and send these to each expert in the panel to make new predictions based upon the feedback; and
- Continue this process of receiving predictions and feedback of replies, until a near unanimity is reached among the experts.

The nominal group technique employs the following steps:

- Constitute a panel of experts to study the subject and give their views in writing;
- Convene a joint meeting of the panelists and discuss each idea among them; and
- Rank the ideas mathematically and repeat the process till a near unanimity is reached among the experts.

In order to narrow down the gap in the assessment of the risk probability, the guidelines tabulated below can be used by the different people asked to assess subjective probability:

Based on the experts' judgment, the subjective probability is evaluated for each risk factor. Thereafter, risk weightage is assigned to each risk factor and total overall risk is evaluated. The procedure for the evaluation and ranking risk is as follows:

Subjective Probability Assignment Indicator in Percentage

Factual statement	100%
Almost likely	90%
Highly probable	80%
Very good chances	70%
Likely	60%
Probable	50%
Doubtful	40%
Improbable	30%
Little change	20%
Unlikely	10%
Highly unlikely	5%
No chance	0%

- Identification of risk factors;
- Comparative weighing of each risk factor;
- Assessment of risk for each factor by experts;
- Aggregation of the opinions of experts; and
- Determination of the total effect of all the risk factors.

Example: Ranking Risk Sources. Consider a project having 11 risk factors. The subjective probability of experts and the pro-rata weightage of each of these risk factors have been determined using the opinions of the experts, assuming that all risk factors are independent. The risk exposure and ranking of risks can be evaluated as shown in **Table 17.9**.

Table 17.9

Analysis of 11 Risk Factors Based on Experts Project Opinions

	Aggregated probability (A)	Weights as ratio of the profit (B)	Weighted impact (AxB)	Normalized impact values (AxB)/Z (AxB)	Ranking
F1	0.43	0.08	0.034	0.086	5
F2	0.51	0.04	0.020	0.051	8
F3	0.35	0.03	0.011	0.026	11
F4	0.47	0.03	0.014	0.035	9
F5	0.37	0.03	0.011	0.028	10
F6	0.31	0.08	0.025	0.062	7
F7	0.33	0.15	0.050	0.012	4
F8	0.36	0.14	0.50	0.126	3
F9	0.49	0.18	0.88	0.220	1
F10	0.42	0.16	0.067	0.017	2
F11	0.36	0.08	0.029	0.072	6

The value '0.22' indicate the peak probability of the source having overall maximum risk exposure, assuming that all risk factors are independent and some of the factor may not occur.

However, some of the risk factors may not occur to the extent as shown above. The calculation of the overall risk exposure, when some risk sources are independent/mutually exclusive/conditional, and have varying cost impact requires advance knowledge of the theory of probability.

17.4.4 Quantifying Uncertainties in Project Duration Estimation

PDM is often used for assessing project duration using one-time duration estimate. This estimation method focuses on a deterministic critical path. It makes this one-time technique static as it does not indicate the probability aspect, which measures the risk. PDM (with three-time estimate), PERT, GERT and Monte Carlo can be used for quantifying the uncertainty prevalent in project completion estimation. The application of Monte Carlo technique for time scheduling of a project is outlined in Appendix P of Chapter 16.

❑ 17.5 RISK QUANTITATIVE ASSESSMENT TECHNIQUE

17.5.1 Techniques vary with the Purpose

Risks analysis approaches vary with the purpose of the project. The choice of technique for risk analysis depends on the nature of the problem being modeled, the amount and reliability of

information available, and the nature of the output required. Requirements of the client and the type of decisions to be made will determine the nature of the required output. For example, there are different approaches for time risk analysis, budgeting project contingencies, analysing risks in selecting a project out of alternate opportunities, analysing economic viability during project feasibility studies, sourcing and selecting contractors and input suppliers, and analysis of contingencies in completion cost estimates. Some of the techniques used in risk analysis are listed in **Table 17.10**.

Table 17.10

Risk Assessment Techniques

Risk Parameter	Risk Assessment Techniques	Example References
Economic viability during project feasibility studies	Expected monetary value (EMV) estimation Expected net present value (NPV) estimation Sensitivity analysis	Appendix L
Project selection risk	Decision tree and Decision networks analysis	Appendix E
Completion time risk	PERT network analysis technique Monte Carlo simulation	Chapter 4 Appendix P
Completion cost risk	Monte Carlo simulation	Appendix P
Time and cost overrun risks	Risk Management Software	Appendix Q

17.5.2   Selecting the Appropriate Risk Assessment Technique

Risk-analysis approaches should match requirements of a project. While, a highly detailed complex technique may be useful for the team performing the risk analysis, other users of the information may not have the same level of understanding. It is therefore necessary to know the merits and shortcomings of the most popular quantitative risk-analysis approaches, which are outlined in subsequent paragraphs.

Monte Carlo.   A simulation technique that computes the project cost or schedule many times, using inputs values selected at random from the probability distributions of costs or durations. The end result is a distribution that gives the possible total project cost or completion time. This simulation technique supported with Oracle Crystal Ball software is given in **Appendix P**.

This technique facilitates easy update of status and analysis of project's completion time and cost. Some project managers believe that the computerised answers are always right, however, it needs experts to analyse the outputs. The Oracle Risk Analysis software for evoluating time and cost overrun analysis introduced in **Appendix Q**.

Sensitivity Analysis.   It is a modeling technique used to determine which risks have the most potential impact on the project. It helps to understand how the variation in one parameter correlates with the base values of others. It uses Tornado. This technique is outlined in **Appendix L.**

By looking at how variables deviate from expectations, project professionals can get a grasp on how risks associated with those variables will affect an initiative. It is best suited for analysing single conditions, but in reality there are several variable changes at the same time. In fact, focus on one change in one single variable is quite unrealistic in a real world situation.

Decision Tree and Networks.   It is a network/tree structuring technique (using decision nodes and probabilistic links. It is explained in **Appendix E**. A decision network/tree reveals various options available on a project. It helps in selecting the best course. Such situations are faced in make and buy decisions. The main difficulty in applying decision network /tree is to structure decision network and assign probabilities, especially if it is complex project.

Note: During implementation phase, the risk assessment techniques are a small part of the overall risk assessment process. There is no such thing as a technique only solution to the problem for dealing rigorously with risk and uncertainty. These techniques must be viewed in context of an overall attitude of mind, which is the framework for risk management. Generally, it is the planners who identify and quantify risks for developing a project risk plan and monitoring future trends. In case of complex high-tech projects, specialist risk consultants can be engaged to analyse the risks, if necessary. Due to limited scope and space, completion time probability and budgeted cost contingency assessment techniques, are covered only briefly in this chapter.

17.5.3   Risk Cost Contingency Allowance

Contingency or the risk cost allowance is the amount that is allocated in the budget to meet the costs of risks and uncertainties in a project. The amount covered under contingency includes minor changes within the scope of work. It also includes minor estimating errors and other unforeseen risks resulting from unusual political, geographical, economic, and natural changes. The evaluation of the contingency, in terms of monetary value, is done by the quantity surveyor at the estimation stage, based on his experience. Traditionally, the contingency is assessed as flat percentage over the estimated basic cost of the project. In the present competitive market, a large contingency allocation in a project may make the contractor's bid price unattractive, whereas, a low contingency amount may result in reduction in the estimated profits. Therefore, it is important to have an in-depth assessment of the contingency amount and its allocation at various levels for exercising better control. Generally, the contingency corresponds to the difference between the maximum risk to the project (usually budgeted with 90% confidence level) and the base estimate.

Project contingency = Budgeted project cost – Base estimate budgeted project Cost

Or

Budgeted project cost = Project base estimate + Project contingencies

The project contingency distribution curve can be plotted by determining the base cost, the expected risk cost, the maximum risk cost, and the standard deviation of the distribution. Maximum risk cost is the amount estimated to cover all risks (90% confidence level) if they were to occur to their full extent. Expected cost is the mean value, which is estimated as having about 50% probability of being exceeded from the base value.

Example 3:   The data in **Table 17.11** shows the cost estimates of the work packages for a project made by the cost estimator. The lower estimate is the minimum cost estimate, the base estimate is the most likely cost, and the last is the maximum estimate.

The tabulated estimate was subject to risk analysis with a view to determine the contingency amount to cater for the unforeseen risk events and errors in estimation.

Estimated minimum cost	=	147.85
Estimated Base cost	=	151.62
Mean Cost	=	155.49
Maximum cost	=	167.00

Table 17.11

Cost Estimates Calculation of the Work Packages in a Project

Item	Work package	Minimum estimate	Base estimate	Maximum estimate	Mean	Variance*
1	A	2.25	2.5	3.0	2.58	0.04
2	B	23.50	24.00	30.00	24.17	2.51
3	C	2.25	2.50	3.00	2.58	0.04
4	D	2.30	2.50	3.00	2.60	0.03
5	E	44.00	44.50	48.50	46.50	0.99
6	F	8.25	8.50	9.00	9.08	0.04
7	G	0.80	0.90	1.90	2.20	0.00
8	H	4.00	4.20	4.50	4.2	0.02
9	I	1.30	1.50	2.00	1.6	0.03
10	J	7.60	8.00	9.00	8.2	0.13
11	K	0.30	0.50	1.00	0.6	0.03
12	L	0.40	0.70	1.00	0.55	0.03
13	M	1.00	1.04	1.50	1.18	0.01
14	N	49.90	50.28	51.00	50.39	0.08
	Total	147.85	151.62	167.00	155.49	3.99

* Variance evaluation formula for triangular distribution is given in **Table 10.4**.

Variance	=	3.99
Standard deviation	=	2.00
Project Contingency	=	Cost at 90% probability (assumed confidence level) – estimated base cost
	=	Mean Cost + 1.2 Standard deviation – estimated base cost
	=	$(155.49 + 1.2 \times 2.0) - 151.62 = 6.27$
	=	about 4.13% over Estimated base cost
Project budgeted cost	=	Base estimate + project contingency
	=	$151.62 + 6.270 = 157.89$

For cost control purposes, the estimator may define estimated minimum cost (147.85) as the target cost for accomplishment and treat the balance budget amount as contingency.

The unbiased project total cost can be determined by running simulations (say 1000 runs) and viewing the simulation results by using computer based Monte Carlo technique. This technique simulates the uncertainty in each cost line item by generating random numbers and enables determination of the probability of over-running the original single-point estimate. Monte Carlo technique is explained in **Appendix P**. In practice, the targeted cost is generally taken as 90% confidence level of the maximum risk cost. It is shown graphically in **Figure 17.3**.

Project contingency = Site controlled contingency + Project reserve
Target budgeted cost = Base estimate + Site controlled contingencies + Project reserves

For allocation purposes, the contingency or the risk cost in a project can be divided into the site-controlled contingency and client-controlled project reserve. Site-controlled contingency covers the risks that can be managed at site by the project manager. The amount assessed for unmanageable risks generally forms a part of the project reserve. Project reserve is earmarked to cover special uncertainties, currency exchange rate fluctuations, abnormal changes in the market prices, cost of major losses, unforeseen environmental changes etc. Project reserves are also referred as funds in addition to the site contingency. The project reserve does not form a part of control estimates, as it is the client reserve for the total project, cost, or the target cost (the budgeted cost).

❑ 17.6   RISK MITIGATION AND ALLOCATION

17.6.1   Risk Mitigation and Allocation Strategy

Risk mitigation measures aim at minimising the loss, damage, or disruption in a project due to unforeseen events. These mitigation measures are described as follows:

1. Risk transfers.   Project risks can be transferred to someone who is more capable of dealing with such problems, such as specialist subcontractors, designers, material suppliers, or by passing the risk to insurance firms. For example, the risk can be transferred:

- To a contractor or designer by the client;

Figure 17.3

Risk Contingency Profile

Ec = Even Chance Estimate
XI = Target Cost'

Cumulative Cost Distribution
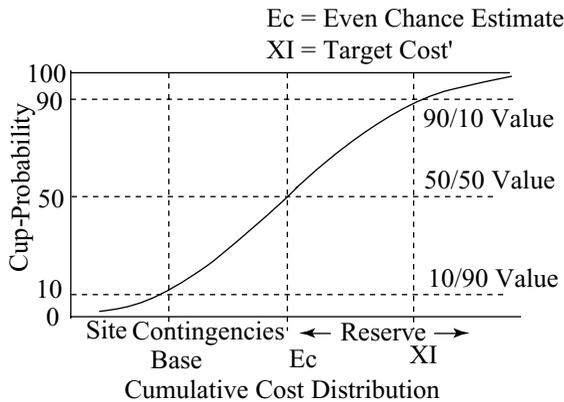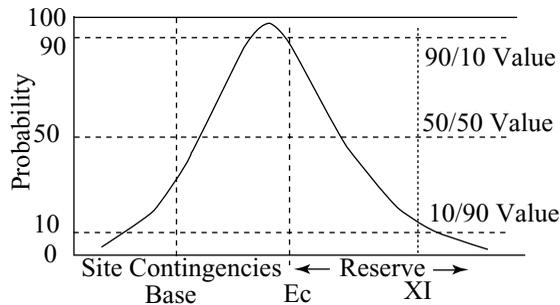
- To a subcontractor by the contractor; and
- To insurance companies or banks by the client, contractor or subcontractor.

2. Risk protection.   Some of the construction business risk protections, which insurance companies provide cover, but are not limited to the following:

- *Property risks*. Fire, explosions, dropping of loads by tower cranes, impact damage and collapse of plant, theft, and transit risks;
- *Performance related*. Design, landslide, collapse, vibration or undermining, and break down of construction equipment;
- *Financial risks*. Loss or profit margin;
- *Commercial risks*. Client not meeting obligation, delay in settlement of claims, money and securities, and performance bonds;
- *Human risks*. Accidents, health and safety, workers, compensation, and third party liability;
- *Environment related*. Natural calamities, such as earthquakes, floods, winds, storms, and epidemics requiring personnel safety, and health care;

- *Ground related*. Underground water courses, locations with geological faults and proximity to railways or roads, and piling processes; and
- *Professional liability insurance*. Protection against professional errors and omissions inclusive of defense costs from claims.

Note: Other available insurance covers include Contractor All Risks (CAR), Erection All Risks (EAR), Electronic Equipment (EEI), Machinery Breakdown (MB), Loss of Profit following Machinery Breakdown (MLOP), Deterioration of Stock (DOS), Civil Engineering Completed Facility Risk (CECR), Contractor's Plant and Machinery (CPM). In most of the construction projects, generally the CAR and EAR insurance policies are taken by contractors. Some other contractors take the CECR policy also. There are some contractors who take the CPM cover.

3. Risk deferred.   Certain project risks can be deferred by time. Activities can be moved to a later date in the project when the adverse effect of events may be minimised or reduced. For example, road bitumen paving scheduled during the rainy season can be postponed to a different season in the year when the weather is drier.

4. Risk reduction.   Project risk reduction aims to reduce either the probability of risk occurrence or the adverse impact on the project or a combination of both. For example, a client may cover the risk of unknown underground soil conditions by suitably wording the contract. Risks related to changes in the scope of the project can be reduced by:

- Well-defined Specifications;
- Detailed site survey;
- Detailed design;
- Completing design before execution;
- Minimising client variation;
- Showing implication of changes;
- Determining logical cost contingency;
- Determining logical float;
- Early involvement of owner's trained/expert project group;
- Appropriate responsibility matrix; and
- Implementing safety/loss control program.

5. Risk acceptance.   Once the risks have been identified and their adverse effects as-sessed, a contingency plan to encounter them has to be organised, developed, and implemented as part of a good risk management strategy. Such a risk will generally comply with one of several criteria, such as no alternative available, cost to transfer risk is very high, probability of occurrence of risk is low but it can have a heavy impact etc. In such eventualities, a client may decide to accept these risks. Unidentified risks fall in the category of risks accepted by the client.

6. Risk avoidance.   Once project risks have been identified, they can be avoided in some cases, by taking appropriate action, such as changing designs, materials, technology and construction methods that may involve additional costs.

7. Risk sharing.   Taking a risk may be resorted to when it is impractical for one party to control the risk. It may be better to manage such a risk with two or more parties. Alternately, the client can retain a part of the risk.

17.6.2   Some Examples of Client Risks Mitigation

In a complex project, the client may consider the following mitigation measures to reduce risks as shown in **Table 17.12**:

17.6.3   Risks Allocation Guidelines

Allocation of risk among parties by the client can be based on following prioritised considerations:

- Allocate the risk to the party that can best control the risk;
- Assign to the which party can best accept the risk at least cost, if it occurs;
- Manage the external risk in order to reduce the contract cost and disputes;
- Transfer/share with the agency/party carry the risk, if transferred/shared, provided the transferee is able to sustain consequences, if the risk occurs; and Recognise that risks and rewards are interlinked.

❑ 17.7   PROJECT RISKS RESPONSE PLAN DEVELOPMENT AND CONTROL METHODOLOGY

17.7.1   Risk Response Plan

Once the risks are identified, quantified, and allocated after mitigation; the next step is to develop a risk response plan. This is a formal document that contains corporate policy, procedures and the delegated responsibility within which the managers manage the risks.

The plan document called risk register identifies the potential risks, it lists the risks in the order of their priorities and the resources needed, response plan for each risk, risk management responsibility, and tentative expenditure contemplated for each risk. Towards the end, it includes list of low priority risks.

Risk register data provides guidelines for making decisions and taking actions. A typical risk register, lists all the identified risks along with other useful information that enables management of each identified, ranked, and prioritised risk. This record should highlight the anticipated timing of a risk and the possible responses for countering it. Each risk event in this register should preferably contain the following information in a tabular form:

Table 17.12

Mitigation Measures to Reduce Risks in Complex Projects

Sources of Risks	Some Typical Client Mitigation Options
Project Scope Changes and Cost Overrun Risks	**Reduce scope changes** by developing scope management plan and risk management policies and procedures, realistic cost estimates and achievable schedules **Reduce cost overruns** by adopting fixed/lump-sum contracts, earmark standby credit and contingency plan, and ensure performance guarantees.
Time Overruns	**Accept** by reimbursing contractor for owner caused delays and by allowing contractor an extension of time for delays beyond his control select an experienced turnkey contractor. Use proven technology. **Transfer** by including contract clauses for penalties, liquidated dam-ages, performance bonus, completion/performance guarantees.
Force Majeure, Ecological, Safety and Security Risks	**Transfer** risk to Insurers/contractor.
Political and Legal Risks	**Accept** that shifting the risk is not effective. However, allow an extension to the contractor for extra time if a public disorder occurs.Reduce by educating the affected public of the benefits of the project.
Financial and Economic Risks	**Accept/Share** if project duration 12 months by making 'price escalation provisions' or 'inflation sharing mechanism', in contracts to attract more bidders, maintain quality standards, and make bids competitive. For foreign exchange requirement, obtain central bank assurances, convertibility guarantees from the host country.
Design and Specifications Risks	**Reduce** by conducting a contractibility review regarding design compatibility with the project scope, enabling cost-effective construc-tion with the proposed construction process, allowing bidders to make comments or ask questions during bidding period and allowing bids with alternate proposals. Consider high damages in case of non-conformance to specifications. **Reduce** by having the design review performed by a person or group not involved with the original design. **Transfer** by allocating risk on engineering consultant for errors created by his negligence. **Avoid** by getting work done through reputed turnkey contractor.
Leadership and Organisational Risks	**Reduce** by managing HR effectively, employing experienced. operational personnel, allowing for staff training and development and having a devoted and committed project leader.
Physical Resources Mobilisation and Utilisation Risk	**Reduce** by negotiating long-term rate and running reliable resources supply contracts
Technology Changes Risks	**Reduce** by using proven technology; consider high damages in case of non-conformance to specifications.
Contractual Disputes	**Reduce** by using lump-sum contract when design is complete, duration known and quantity, quality and type of work is fully known; using the turnkey approach to transfer all design and construction risks to the contractor; meeting client's contractual obligations; and getting the Disputes Review Board (DRB) to pay valid claims promptly.

- Risk title and description;
- Likely causes that can trigger risk event;
- Description and quantitative range of likely impact on project objectives, where appropriate;
- Nature of interdependence;
- Anticipated time and probability of occurrence;
- Possible responses for countering risk;
- State of risk after effective response; and
- Individual/department responsible for managing risk.

Risk baseline plan, in addition to risk register, also includes nature of risks, probability of occurrences, impact in delayed working days, and exposure in amount and responsibility.

A risk response plan ensures that appropriate risk warning tools are in place to efficiently handle risks. This is achieved by developing an effective warning system in form of a contingency plan. The risk response plan, prepared after due consideration of the above factors should document the procedures that will be used to manage risks. The risk response should be finalised after it is agreed by all parties involved and its implementation is entrusted to a nominated person. However, the project manager remains accountable for all risk related decisions at the project site.

17.7.2 Risk Response Control

Controlling risk is the process of implementing and updating risk response plan. Risk control aims at implementing the risk response plan by tracking identified risks, monitoring residual risks, identifying new risks, and documenting changes from the projections in the risk register to handle risks in a manner that project's objectives are achieved efficiently and effectively. It is based on proactive rather than reactive approach by having the right measures in place and improving them constantly. There are no readymade solutions to minimise risks, but the following remedial measures can assist in controlling them:

a. Adjust plans, scope of work, and estimates to counter risk implications.
b. Monitor risks regularly, evolve alternate plans to manage foreseeable risks, when necessary.
c. Make timely decisions.
d. Keep all concerned informed about possible risks.

Updating Risk Management plan includes corporate strategy for risk mitigation, roles and responsibilities of stakeholders, reviewing and reporting frequency to Project corporate and project management office (wherever applicable), risk threshold for major still-to-occur risks, watch list for low exposure remaining risk, and emerging additional risks.

The monitoring of risk's response plans serves many purposes. The monitored records form the basis for making risk related decisions. Such generated statistical data lead to greater understanding and envisioning of risks in future projects. Risk reports reveal the effectiveness of the risk management process and bring out the strengths and weaknesses at various levels of management.

❑ 17.8   MULTINATIONAL CORPORATION (MNC) OPERATIONS RISK

17.8.1   Objective of MNC

A Multinational Corporation (MNC) deals in producing and selling of goods and/or services in more than one country under global environment. Generally, its parent company is located in home country and it has foreign subsidiaries interact among the units. It is based on the doctrine of comparative global advantage, i.e. each nation can specialise in production and export of goods and services that it can produce relatively economically and import those that other nations. MNC's can produce/trade more efficiently. The main objective of MNC financial management is to maximise shareholders wealth as measured by share prices.

Risks encountered by an MNC in a foreign country can be broadly divided into political and economic risks, and risks on account of foreign currency rate variation.

17.8.2   Political and Economic Risks

These risks include but are not limited to those mentioned below:

Political risks.   The indicators are frequency of change in govt., extent of violence and insurgency, conflicts with other state, lack of social cohesion, attitude towards private enterprises, attitude towards private enterprises, expropriation and nationalisation tendency, stringent regulatory mechanism, currency convertibility restrictions, uncertain property rights, illegal capital flight by nation's citizen, corruption in pubic dealing and legal system, instability in free market economy, inadequate incentive for investment, frequent changes in statutory requirements for MNC's operations, and scarcity of human resources, such as highly skilled labour, supervisor, and engineers.

Economic risks.   The indicators include high rate of inflation, high rate of money expansion, fiscal irresponsibility, uncontrolled deficits relative to GDP, high tax rates, wasteful government spending, low growth rate per capita GDP, large govt. deficit relative to GDP, lack of infrastructure necessary for growth, controlled exchange rate system, instability in free market economy, and extent of state subsidies on consumer goods.

Indicators like Profit Opportunity Recommendation (POR) ratings and assessment determined by subjective assessment of a panel of experts can be used to assess the extent of a country's political and economic risks. But there is no unanimity on how to mitigate these risks. Some of the political and economic risks mitigation options to MNCs include insurance of assets against losses, encouraging overseas equity participation, negotiating the concession agreement by incorporating suitable clauses, and structuring investment. Economic policies should focus on planned divestment, aiming at short-term profit maximisation and developing local stakeholders.

17.8.3 Foreign Currency Exchange Rates Variation Risks

Foreign Currency Exchange exposures refer to the degree to which MNC is affected by changes in exchange rate. Foreign Exchange Risk Management needs a specialist to manage changes in exchange rates. The Foreign Exchange exposures can be measured in several ways. The three basic types of measures are accounting exposures, transaction exposures, and operating exposures.

1. *Accounting exposures* (also called as translation exposure) imply conversion of the financial statement of foreign operations from foreign currency to home currency for reporting and consolidation purposes. The conversion from previous report to current report may result in gains or losses.
2. *Operating exposures* show changes in amount of future operating cash flow caused by changes in exchange rate.
3. *Transaction exposures* refer to the changes in the value of foreign currency of binding contracts. It is on account of activities that have occurred in the past and are still to occur in future exposures.

Commonly adopted simple course for measuring extent of risk is to convert the financial statement of foreign operations from foreign currency to home currency for reporting and consolidation purposes. The conversion from previous report to current report will adjust the resulting gains or losses. The recent trend is to follow IFRS code for financial accounting and reporting purposes. This will be done by revising existing accounting standards to make them compatible with IFRS. [Source accessed internet for International Financial Reporting Standards (IFRS), Interpretations and the framework adopted by the International Accounting Standards Board (IASB)].

Foreign Exchange Risks are mitigated by 'hedging' the currency exposure. Hedging implies establishing an offset currency position by locking home currency value for the currency exposed with currency hedged. Hedging strategy/techniques depend upon currency's forecast of variation trends. These can be broadly divided into two categories based on whether the exposure results are expected to depreciate or appreciate.

1. **Currency depreciation anticipated**. In such situation, respond by forward selling of local currency; reducing holdings of local currency cash, securities and receivables; delay collection of hard currency receivables; and speed up imports of required hard currency goods and services.
2. **Currency appreciation anticipated**. In such situation, respond to the demand by forward buying of local currency, increasing holdings of local currency cash, securities and receivables, speed up collection of hard currency receivables, and delay imports of required hard currency goods and services.

❏ 17.9   PERFORMANCE INTERNAL AUDIT GUIDELINES

17.9.1   Objectives

Performance at a given point of time reveals the extent to which the project's purpose and its speci-fied objectives are accomplished. One of the best acknowledged methods for controlling risks is to conduct performance internal audit. The performance internal audit examines and documents the effectiveness of risk response plan. It is the responsibility of corporate or project management to ensure that performance internal audit is conducted at regular intervals. Risk audit may include routine project audit meeting or audit by its special team with the third party auditors. The object and guidelines for conducting project performance internal audit are outlined in subsequent para-graphs. Performance at a given point of time reveals the extent to which the project's purpose and its specified objectives are accomplished.

Audit as defined in ISO 19011:2002, is a systematic, independent, and documented process, for obtaining audit evidence and evaluating it objectively to determine the extent to which the audit criteria are fulfilled. Depending upon the beneficiaries, Audit can be broadly divided into two cat-egories i.e. external and internal audit. An external is financial statement audit carried out by an in-dependent experts for the benefits of the stakeholders and to meet statutory requirements, whereas, internal audit is performed by entity members or outsourced experts for monitoring and appraisal of the entity's performance of internal control system. In particular for a project, performance internal audit focuses on audit of economy, efficiency and effectiveness with which the entity makes use of its resources in carrying out its responsibilities. It embraces:

- Audit of the internal economy of administrative activities in accordance with sound adminis-trative principles and practices and management policies;
- Audit of the efficiency of utilisation of human, material, financial and other resources, includ-ing examination of information systems, performance measures and monitoring techniques and procedures followed by audited entities for remediating identified deficiencies; and
- Audit of the effectiveness of performance in relation to the achievement of the objectives of the audited entity and audit of the actual impact of activities compared with the intended impact.

It may be noted that internal audit can focus only on a part of the selective internal control activities of the project over a period of time and can be performed after completion of each phase: semian-nually, annually, or on completion of the project to improve performance or to bring out lessons learnt. Performance internal audit objectives are stated in terms of what the audit intends to accom-plish and/or the questions the audit will answer. The questions may include areas, such as those relating to performance of project organisation, quality, time, resources, cost and risk management systems for the accomplishment of overall project objectives. In short, performance internal audit assists in monitoring and controlling performance to achieve project's objectives economically,

efficiently, and effectively by scrutinising whether the things are being done in a right way and the right things are being done, and recommend timely corrective actions for the accomplishment of overall project's objectives.

Performance internal audits may be carried out by external agencies or the corporate internal audit group cosourcing with some external experts. Internal audit team working with construction corporate can determine the scope, team composition, and terms of reference of the audit. Performance internal audit is a knowledge-based exercise in which conclusions emerge from observations and interpretations. It calls for special skills, knowledge and competence of the audit team. The oracle risk analysis software is introduced in **Appendix Q**.

Performance internal audit is a vast and complex subject. The techniques employed by the audit team will vary from project to project. These techniques include evidence gathering, opinion surveys, benchmarking, interviews, case studies, quantitative data analysis, data spread analysis, computer aided auditing techniques, and use of tools, such as internet, data auditing and management software. Due to limited scope, this Appendix does not cover the auditing techniques and data processing methodology.

17.9.2   Typical Focus Areas of Performance Internal Audit

Performance Internal Audit Focus.   In context of a construction project, the project's objectives are generally stated in terms of project scope, work specifications, budgeted costs, completion time, resources constraints, contract conditions, and so on. Execution of project work needs design and drawings, finances, human resources, procedures, and an organisational set up to achieve objectives efficiently, effectively, and safely. Conducting an audit will involve systematic collection and analysis of information. This analysis is not limited to appraising what is accomplished in relation to costs but also whether the project is progressing as planned and if not determining the root causes. It is necessary that the audit objectives, scope, that is, the boundary of audit in terms of the segment of programme and the time period of operations over which the audit tests are to be carried out must be well defined. In a typical construction project the area of Performance Internal Audit and the typical focus areas to be considered for audit include the following:

1. *Project Contracts and Sub-Contracts*. Pre-qualification criteria, policies and procedures for procurement contracts, pre-qualification key contract provisions, implementation of obligations of Client and Contractor, contract defined documentation and procedures, records of contract related meetings and commitments, contract amendments, policies and procedures regarding contractual disputes, and risk forecasts.
2. *Project Organisation and Responsibilities*. Project quality policies, managerial responsibility, authority and interrelationship, management review meetings, appropriate performance reporting to senior management, managers and staff turnover, channels of communication, staff training, and risk forecasts.

3. *Project Policy Documents and Data Control Systems*. Documented policies, approvals, changes, and risk forecasts.
4. *Finance and Accounting Systems*. Investment analysis, sources of funding, financial statements analysis, and risk forecasts.
5. *Project Work Scope and Integration System*. Scope definition, work breakdown structure, design concept, status monitoring, change controls, integration process, performance recording, scope verification, scope status reporting, scope control documents, and risk forecasts.
6. *Product Design Control System*. Consultants selection, design concept, drawings codification, design and drawings submission and approval schedule, schedule deviations and their effects, design verification system, design changes, specification standards, and risk forecasts.
7. *Product Quality Management System*. Quality planning, quality management system, quality assurance policies, quality control system, construction method statements, rework analysis, functional verification, quality acceptance, and risk forecasts.
8. *Construction Works Time Planning and Control System*. Planning assumptions, activities identification, activity duration estimation, networking, time-cost trade-off, scheduling activities using optimum resources, monitoring processes, controlling time schedule deviations, and risk forecasts.
9. *Materials Procurement and Management Systems*. Vendor/supplier pre-qualification/selection, classification, wastage, estimation processes, procurement, inventory, productivity, and risk forecasts.
10. *Manpower Procurement and Management Systems*. Classification of workers, workers' productivity standards, workers' requirement forecast, grouping project workers, labour accounting methodology, productivity, labour incentive schemes, causes of low labour productivity, and risk forecasts.
11. *Equipment Procurement and Management Systems*. Requirement, selection criteria, acquisition options, productivity, preventive maintenance, and risk forecasts.
12. *Cost Accounting and Controlling Systems*. Accounting systems, estimating and bidding, contract evaluation, job site accounting and controls, billing procedures, contract cost status, contract revenues, construction equipment, scope changes extra costs, claims, accounts receivables, liabilities related to contract, and risk forecasts.
13. *Workers' Safety Management Systems*. Regulatory requirements, safety measures, safety audits, and risk forecasts.
14. *Project Risk Management Systems*. Identifying, quantifying, mitigating, allocating, planning risk response plan, controlling risks, and risk forecasts.

The above mentioned focus areas for audit are generally applicable to a typical construction project's performance internal audit. The above does not include Project Formulation and Appraisal and Public Private Partnerships (PPP) projects (see Public Auditing Guidelines of Comptroller and Auditor General of India for PPP Projects).

Performance Interim Audit Focus. Interim audit focuses only on a part of the selective internal control activities of the project over a short period of time and can be performed after completion of each phase, semi-annually, annually, on completion of the project to improve performance or to bring out lessons learnt. To quote an illustration, the mandate of an internal audit of a 24 km water supply pipeline after the 6 months of its start, can be limited to the following areas and activities:

1. **Engineering**. Adherence of design work/deliverables to submission and approval scheduled dates; progress is correctly measured and reported in a timely manner; changes to engineering designs are authorised and properly supported.
2. **Procurement of goods and services**. Competitive bidding is conducted in accordance with procurement policies; procurement of long lead time equipment/supplies is properly timed to meet budget earmarked and project requirements; written contracts are reviewed and approved in accordance with project's authority levels and legal department review requirements; contractors and sub-contractors are properly managed and monitored.
3. **Project cost and scope management**. Project forecasts and estimated costs-at-completion are prepared and timely updated and subjected to proper variance analyses; and trends and changes in scope are reviewed and communicated, properly approved, and adequately documented.
4. **Project cost accounting**. Project costs and liabilities are adequately tracked, recorded, and monitored; project disbursements are properly approved, aligned with contract terms and adequately supported, project costs are approved, aligned with cost estimates and adequately supported
5. **Management reporting and document management**: Management reporting is adequately detailed and timely to facilitate effective monitoring of progress and costs; project schedules and other key project documentation are adequately maintained and updated timely.

In particular, risk analysis should be carried out with reference to each audit area set in the audit mandate. It can also include the audit of Risk Management Plan Plan described in **Section 17.2** and the Project Risk register.

17.9.3 Planning of Performance Internal Audit

Audit planning establishes the objectives, scope, and the audit approach. Audit program sets the time frame, audit requirement, and necessary procedures to conduct the audit and to make assessments against audit criteria. Focus of audit planning is to develop an approach for the expected nature, timing, and extent of the audit procedures. Proper planning of the audit work helps to ensure that appropriate attention is devoted to important areas of the audit, potential problems are identified and the work is completed expeditiously. Audit planning includes but is not limited to the following:

- Objectives of the performance internal audit, theme-wise, in statement or question form;
- The scope and program/subject of audit including the time-frame;
- Audit criteria (one or more) against each audit objective;
- Evidence analysis techniques to be used;
- Assignments and responsibilities, data gathering, supervision and data analysis;
- Expert or consultancy services and outsourcing, if required, along with the explanatory notes;
- Risk analysis, audit area-wise, where applicable;
- Sampling techniques used or to be used for selection of the units and data;
- Audit test programmes;
- Series of actions/steps expected at each stage for entity involvement and cooperation;
- Planning of Entry and exit conferences;
- Periodic reporting to the supervisory officer and the Corporate Headquarter;
- Coordination structure when different teams conduct audits at different locations; and
- Time-schedule for field audit, report writing, forwarding the draft report to the entity, report approval, printing and final presentation.

17.9.4 Conducting of Performance Internal Audit

This section contains the practices and procedures that should be followed by the audit team during conduction of the audit and covers various stages of performance internal audit from commencement of the audit up to the development of the audit findings and recommendations.

Commencement of Audit.   An opening meeting with representation of the auditee's management is needed in accordance with the following:

- Introduce the members of the audit team to the auditee's management;
- Review the scope and objectives of the audit;
- Provide a short summary of the procedures and methods to be used;
- Establish communication links;
- Confirm the facilities and resources needed by the audit team;
- Confirm the time and date for interim and closing meetings; and
- Respond to any questions about the audit plan.

Collection of Evidence.   Internal auditors should identify sufficient, reliable, relevant, and useful information to achieve audit's objectives. Evidence can be collected by interviews with the staff and workers and observations of the practices and conditions in the areas of concern. Suspected conditions of nonconformity should be recorded for further investigation and information gathered should be substantiated by other independent sources, such as records and physical observations or measurements. If the objectives of the audit appear to be unattainable, the lead auditor should report the reasons to the auditee and client.

Documentation of observation.   All relevant audit observations must be documented so that the audit team can evaluate information and determine potential nonconformities. The observations must be clearly stated and supported with evidence. The observation of nonconformity should be reviewed and confirmed by the lead auditor and acknowledged by the auditee's management.

Developing findings.   Audit findings are identified by relating audit observations to audit criteria. Audit observations are based on the analysis of evidence collected during the audit. Audit findings should be developed and evaluated throughout the various phases of audit. Potential findings identified in the planning stage or during the preliminary study should be followed up in the detailed examination phase of the audit.

In keeping with the principle of objectivity, the audit team should include both positive and negative findings as a part of the report. This usually results in client being more receptive to the findings. At appropriate stages in the audit cycle, impact analysis may be carried out while developing the audit findings and recommendations.

Developing recommendations.   For developing recommendations, the audit team should identify the underlying root cause(s) of a finding, as this forms the basis for the recommendation. The audit team may identify a root cause-and-effect chain and have the option of reporting the findings at different points in the chain. In this situation, the auditor should highlight the most critical deficiencies in the chain. A quality audit should yield recommendations, which, in most cases, be acceptable to the entity.

Recommendations emerge from identification of the cause and impact of audit findings. Addressing the following questions will assist the auditors in developing practical recommendations:

1. What needs to be done?
2. Why does it need to be done?
3. Where does it need to be done?
4. When does it need to be done?
5. How does it need to be done?
6. Who is to do it?
7. What is the expected impact, if it is done?
8. Are there any potential risks involved with the implementation of the recommendation?
9. Is it practicable to implement the recommendation?
10. Is the recommendation cost-effective?

The recommendations are logical conclusions of the performance internal audit process that relate to the causes of audit findings. The stage at which the recommendations should be developed and communicated cannot be prescribed uniformly. Recommendations require careful examination to ensure that they are practical and add value.

Since recommendation is the culmination and crux of the performance internal audit, they should be presented distinctly to enable the client to maintain an inventory of recommendations for all performance internal audits and carry out follow-up processes to take the performance internal audit to its logical conclusion.

Corrective Action Follow-up. The auditee is responsible for corrective actions related to audit findings. Corrective action and follow-up audit should be completed within an agreed time period. After verification of corrective action, the audit organisation may prepare a follow-up report and distribute it in a similar manner as the original report.

Exit Conference.   In audit of all entities, the audit team should conclude the audits with an exit conference/meeting with the auditee management of that entity. All audit observations must be issued to the relevant personnel at least one or two days before the scheduled exit conference. The exit conference is an opportunity to discuss the audit findings with the auditee management. This also affords opportunity to the audit team to clarify any points of doubt that the entity may like to raise. The minutes of exit conference should be recorded and endorsed to the entity.

Closing the Audit. At the conclusion of the audit, a closing meeting should be conducted to explain the audit findings to the auditee's management. The objectives and results of the audit should be clearly presented to assure the understanding of management.

Record Retention. Records of the audit should be retained as agreed by the auditing organisation and the client in accordance with regulatory requirements.

17.9.5   Performance Internal Audit Report

On completion of each audit assignment, the auditor should prepare a written report stating the audit observations and conclusions in an appropriate form, its content should be easy to understand, free from ambiguity, supported by sufficient, competent, and relevant audit evidence, clear, objective, complete, accurate, constructive, timely and concise.

Draft performance internal audit report.   The draft performance internal audit report should be prepared exactly similar in form and content as the final report with the exception that the entity may expect details to enable it to provide a response. The purpose of preparation of the draft report is to seek formal responses from the auditee management.

Forwarding of the draft report.   The auditors may forward the draft audit report to the appropriate entity. It may contain the following:

- subject of the performance internal audit and reference to previous dialogues;

- summary of major audit findings and recommendations along with the risks and materiality of the issues;
- invitation to a formal discussion and presentation of the audit findings and conclusions; and
- the expected value additions to the programme management, if the recommendations are implemented

Final report.   On receipt of the response on the draft report from the top management, the auditor should prepare a copy of the final report. The signed copies of the report should be forwarded to the concerned personnel. The contents of the final report may include:

- Title: the subject of the performance internal audit;
- Audit objectives;
- Audit methodology;
- Major audit findings and analysis;
- Recommendations and follow up program;
- Lessons learnt;
- Acknowledgement;
- Appendices containing Graph, charts, diagrams, photographs, etc.; and
- References.

17.9.6   Salient characteristics of a good report

The audit reports should be:

1. Complete. It means that all pertinent information required satisfying the audit's objective, including the information relating to the scope, criteria, evidence, conclusions, and recommendations should be available in the report.
2. Accurate. It implies that the evidence gathered and the conclusions are correctly reflected.
3. Objective. It is ensured through fair conclusions and balanced content and tone.
4. Convincing. The results of audit are presented persuasively and the conclusions and recommendations followed logically from the facts presented.
5. Clear. It should be easy to read and understandable.
6. Concise. The report should be of optimum size to convey the audit opinion and conclusions.
7. Balanced. It includes improvement opportunities as well as good performance.
8. Consistence. It should not contain contradictory findings or conclusions in similar contexts or the conclusions on the same segment in different sections or parts of the report are not incompatible.
9. Constructive. It manifests a remedial approach rather than a critical approach and includes appropriate recommendations.
10. Timely. The report adds value to the entity if it is timely

17.9.7 Benefits of Conducting Performance Internal Audit

Performance internal audit is an assessment of efficiency and effectiveness of the project, with due regard to economy. It addresses the issues of inputs, processes, outputs (products), and outcomes (impact). Apart from the question whether the things are being done the right way, it also addresses the question of whether the right things are being done; in other words, it also focuses on what is not being done rather than only on what is being done. Performance internal audit can enhance the project economy, efficiency, and effectiveness in achieving project objectives. It can minimise time and cost overruns by giving timely warnings. It is for the corporate management to determine as to whether such an audit is required or not, and if required to customise its scope and mandate.

For an in-depth study, the readers can go through 'Performance Internal Auditing Guidelines of SAI India' (accessed on 19.11.12 at: www.Saiindia.com); 'Public Auditing Guidelines of Comptroller and Auditor General of India for Public Private Partnerships (PPP)'; ISO-19011-2002; Audit and Accounting Guide 'Construction Contracts' of American Institute of Certified Public Accountants, Inc.; and 'Technical Guide on Internal Audit of Construction Industry' published by the Institute of Chartered Accountants of India. These guidelines provide the leading practices for planning, implementation, reporting, follow-up processes and quality assurance for performance internal audits.

❑ 17.10 THE HUMAN SIDE OF RISK MANAGEMENT

Risk analysis cannot be mechanised and the most important characteristics needed to analyse and manage risk is an appropriate frame of mind or the risk-taking attitude of the project manager.

The risk-taking decision depends upon the utility or the pleasure or displeasure one derives from the expected outcome. The utility theory explains how, not why, rational people sometimes prefer outcomes which do not necessarily have the highest monetary value. The utility theory suggests that instead of maximising the EMV, people maximise their own expected utility or what pleases/satisfies them. The equation that describes the utility curve is the utility function. Utility functions vary from person to person. Also, the utility function of an individual may not be identical to the utility function of an organisation that is employing him. Behavioral scientists have classified individuals with risk tolerance characteristic into three categories, i.e. risk averter, risk neutral and risk seeker. The utility curves showing these characteristics are shown in **Figure 17.4**.
In the above **Figure 17.4**:

- The Y-axis represents utility, and it shows the project manager's willingness to take decisions gladly;
- The X-axis reflects the money at stake; and
- The shape of the decision-makers tolerance curve indicates the response to alternate decisions.

Figure 17.4

Utility Curves Showing Risk Tolerance Characteristics
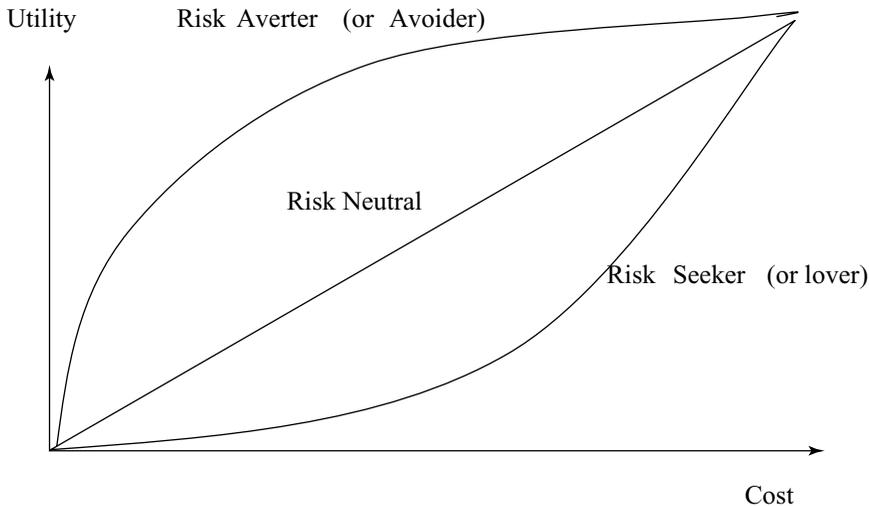
In the case of risk averters, the utility rise is marginal as the slope of the curve which is at risk averter decreases with the increase in expected monetary value. In other words, a project manager is cautious and conservative, as his tolerance reduces when more money is at stake. More money increases his utility only very slightly. On the other hand, a risk seeker or risk taker may be willing even to pay a high penalty in order to gain a higher uncertain outcome. A risk neutral project manager with linear utility curve is most likely to use the expected outcome as the decision criterion and will act only when the expected outcome is positive.

It is important to note that the knowledge of risk analysis tools and techniques is necessary to manage risks, but it is not sufficient in controlling risk. The final piece of the jigsaw puzzle is the human being. This involves gaining a clear understanding of the human perception of project risk and uncertainties. It is also important that the risk-taking attitude of the project manager and the characteristic of the project should be compatible.

❑ 17.11   ROLE OF THE PROJECT MANAGER IN MANAGING RISKS

A project manager's capability to accomplish the mission in a large-sized, modern construction project is a prime requirement of professional skills in risk management. His role in managing risks includes the following:

- Estimating cost and time contingency allowances and allocating these in commensurate with major risks and uncertainties that are identified;

- Regularly monitoring risk response plan and reviewing these with the concerned personnel in order to reduce misunderstandings and ensure that the full spectrum of uncertainties is exposed;
- Adopting methods for allocating the remaining risks to the various parties in a way that will optimise project performance;
- Recognising that risks and rewards go hand-in-hand and, that the allocation of a risk to a party should be accompanied by a suitable incentive;
- Keeping an open-minded approach to innovative solutions to problems; and
- Making appropriate timely decisions.

❏ 17.12   THE BENEFITS OF MANAGING PROJECT RISK

The overall awareness of risk exposure and the methods of handling risk add to the effectiveness and efficiency of the project management. This is due to several reasons:

- The risk response development process gives an insight into the project management process. Accordingly, the issues/problems of the project are clarified, understood, and allowed for right from the start;
- A pre-planned contingency plan provides clearer definitions of the specific risks associated with a project.
- It allows prompt, controlled, and pre-evaluated responses to any risk that may materialise;
- The structure and definition of the project risk are continually and objectively monitored. This in turn reduces exposure to project risks;
- Risk response decisions are supported by a thorough analysis of available data;
- A fully documented risk management process, builds-up a profile of historical risk to allow better modelling for future projects;
- It encourages problem-solving and provides innovative solutions to the risk problems within a project; and
- A risk reporting framework avoids sudden risk shocks.

It is sometimes argued that the risk identification process induces negative and cautious attitudes among the team or the project sponsors. Contrary to this, it can also be said that the risk identification process, if developed with the participation of the project team, enables effective management of projects by:

- Identifying the participants who can be entrusted with the management of risks, and
- Creating environments for managing risks efficiently and effectively among the concerned people, as they become aware of the risky situations well in advance.

The process of breaking a project down into its sources of risk and systematically analysing them ensures that managers develop a much more realistic feel for the project and its range of possible outcomes.

Risk analysis supplements the professional judgement. However, risk analysis is not a substitute for professional experience, judgment, and the attitude of the appropriate decision -makers. Project managers cannot stop the fast-changing, unstable, risk-prone environments, but they must prepare themselves for managing the impacts of risks to their projects. This in turn reduces exposure to project time, cost, and performance risks.

APPENDIX Q

Primavera Risk Analysis Software: An Overview

❑ Q.1 INTRODUCTION AND SCOPE

A typical Project Risk Analysis software can provide quick and easy techniques for determining contingency and risk response plans as well as comprehensive means of using Monte Carlo simulation for analyses. It acts as a decision support tool for determining confidence levels regarding project costs and schedules. It can then produce a variety of reports, such as risk histograms, tornados, and scatter plots that enable users to easily identify risk drivers. The contents of this Appendix covering risk analysis software salient features are briefly outlined below with illustrations from Primavera Risk Analysis software.

❑ Q.2 PRIMAVERA RISK ANALYSIS SALIENT FEATURES

Oracle's Primavera Risk Analysis software provides the tools that enable the corporate and project management team to model risks and analyze the cost and schedule impacts. Primavera Risk Analysis provides an integrated cost and schedule risk analytical solution by integrating directly with project schedules as well as cost estimates to model risks and uncertainty for the Primavera project management applications and Microsoft Project. It provides the tools to model risks and analyse cost and schedule impact of mitigation and analysis of the sensitivity. It integrates

risks directly with project schedules and costs. It provides a comprehensive means of reporting risks with certain confidence levels regarding projects. It facilitates Risk Register development and determination of contingency and risk response plans. It has many advanced features which include, producing a Tornado Graph to identify key risk drivers and pinpoint the task sensitivity; determining the combined probability of achieving given budgets and completion dates; performing what-if analyses, and forecasting Probabilistic Cash Flow. It produces risk analysis reports in a variety of formats. The contents of this section are briefly outlined below with Primavera Risk Analysis software.

Schedule Check.   These features enable users to evaluate schedule maturity and risk readiness by examining common scheduling problems that can affect deterministic schedules. The Schedule Check report provides the rationale behind each check and explains how it can affect risk analysis. It also provides a list of the activities identified.

Templated Quick Risk feature uses a template approach to assign uncertainty risk distributions to tasks based on WBS (work breakdown structure), activity code, user-defined field or filter. These templates make it easy to model task uncertainty.

Risk Register.   With this feature users can integrate pre-developed risk registers as well as define new ones (see **Figure Q.1**). It also automatically integrates identified risk events into the schedule by creating a risk event plan, which users can then analyze to determine both key risk drivers and the cost-effectiveness of the identified mitigation strategies.

Risk Register Wizard can enables users to quickly create new risk registers, define risk scoring criteria, enter qualitative risk assessments, and mapping risks to scheduled activities. Users can then gather quantitative assessments and more detailed information in the resulting risk registers.

Risk Analysis.   It uses advanced Monte Carlo-based cost and schedule analysis to estimate uncertainty, task existence, probabilistic branching, fixed-cost uncertainty, variable-cost uncertainty, resource uncertainty, conditional branching, and weather modeling. In addition, users can make strategic decisions about project selection through portfolio models as well as traditional project-level risk analysis against individual or linked schedules.

Distribution Graphs for Reporting (see Figure Q.2).   It can enable users to:

- Determine confidence levels, schedules, and cost contingency;
- Report confidence levels with regard to finish dates, costs, float, internal rate of return, and net present value;
- Drill down through the interactive report to identify confidence levels at every step including key milestones and stage-gate review points; and
- Tab between cost and schedule-based views with the ability to drill down through the integrated tree control and filter by task or resource.

Figure Q.1

Primavera Risk Register
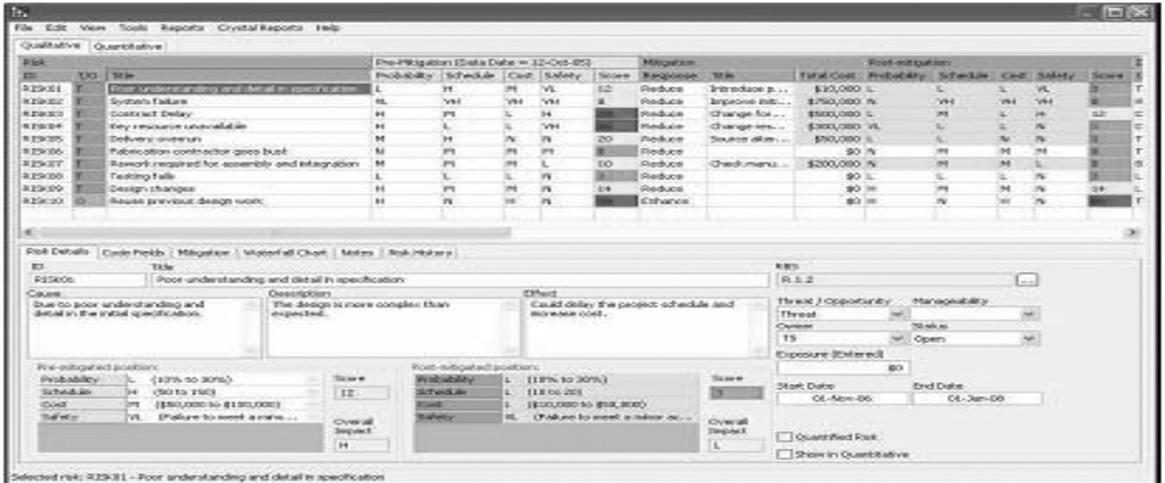
Tornado Graph for Sensitivity Analysis.   It can help users identify key risk drivers and

Figure Q.2

Distribution Graph
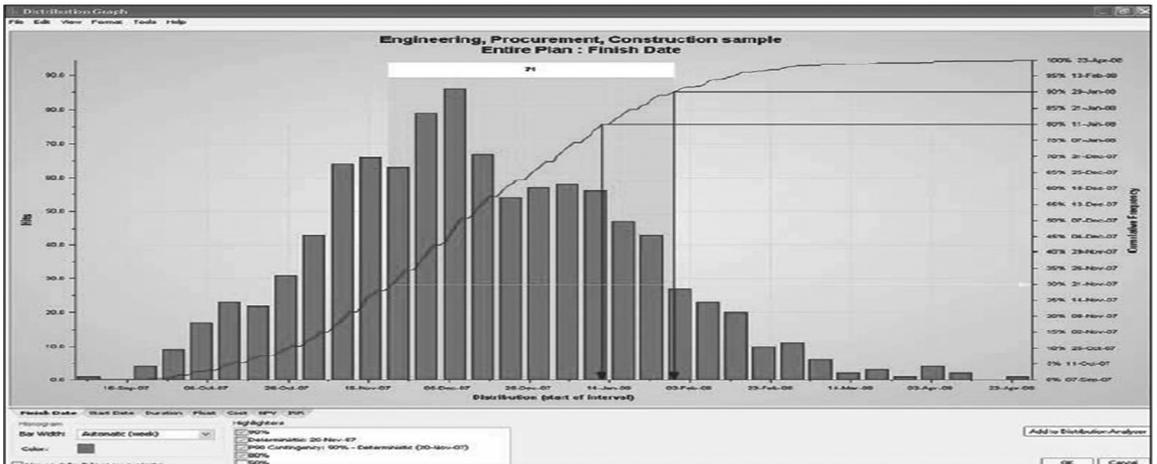
pinpoint the sensitivity of each task from performing as per set expectations. Alternatively, users can employ cost-sensitivity reports to isolate the most-cost-critical tasks or risk events. Interactive drill-down risk tornados enable quick and easy risk driver determination to report key risk drivers.

Figure Q.3

Tornado Graph
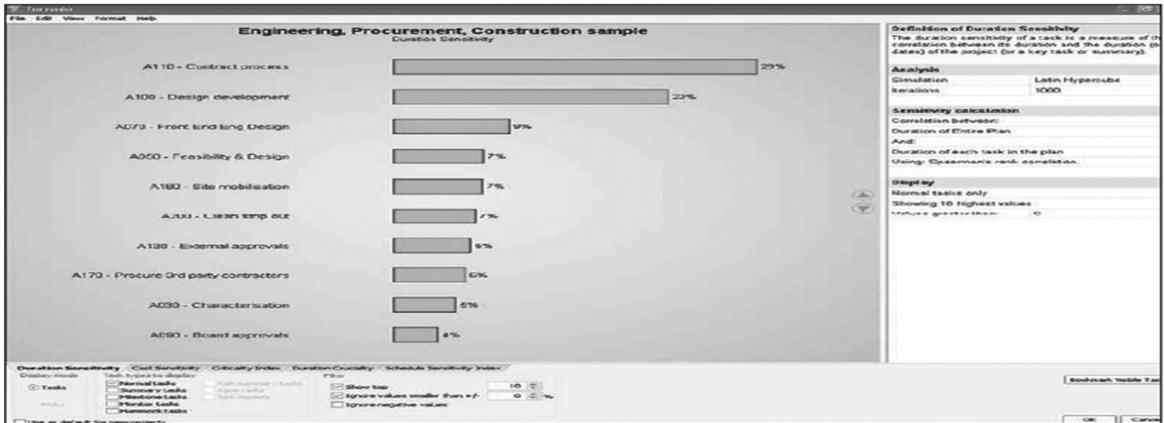
Summary Risk Report. It lets users quickly share the results of their risk analyses via summary risk reports. Users simply select the activities, risk inputs, risk outputs, and Primavera Risk Analysis creates an interactive report that includes the links between inputs and outputs in the report and activities in the schedule.

❑ Q.3 SOFTWARE LEARNING APPROACH

The best way to easily learn Primavera Risk Analysis is to use its tutorials. They give practical examples of how to use many of the features in the Primavera Risk Analysis software. They also contains Templates Quick Risk and Probabilistic Cash Flow guidelines:

1. **Planning Tutorial**. It focuses on entering into the project plan. The steps include starting a new project, entering tasks, creating milestones, entering task durations, incorporating the summary tasks, adding logic to define task relationships, viewing the precedence network, assigning resources and costs to each task and validating the plan. Primavera Risk Analysis can read the project data from Primavera P6 preferred Version 8.1 or later and MSP.
2. **Risk Tutorial Part 1**. It aims at creating risk models in Primavera Risk Analysis. It covers a brief introduction to Risk Analysis, modeling task durations, entering duration uncertainty, task existence risk, running the Risk Analysis, interpreting results, copying the risk graph to the clipboard, examining the criticality Index and developing Risk Schedule.
3. **Risk Tutorial Part 2**. It introduces probabilistic branching and probability is assigned to each outcome of the branch. The various topics covered in this part include probabilistic branching, adding costs to tasks and adding uncertainty to task cost.
4. **Templated Quick Risk**. The template Quick Risk feature uses a template approach to assign uncertainty risk distributions to tasks based on WBS, activity code, user-defined field or filter. These templates make it easy to model task uncertainty.

5. **Risk Register Wizard**. In this Wizard, users can quickly create new risk registers, define risk, scoring criteria, enter qualitative risk assessments and map risks to scheduled activities. It also enables quantitative assessments and more detailed information in the resulting risk registers.

Risk Report.   Primavera Risk Analysis can produce variety of risk reports. These include but are not limited to the following:

- Risk Register Summary.
- *Project Duration Sensitivity* Tornado Graph. The duration sensitivity of a task is a measure of correlation between duration of tasks and duration (or dates) of the project (or a key task or summary).
- *Project Cost Sensitivity Tornado Graph*. The cost sensitivity of a task is a measure of the correlation between its cost and the cost of the project (or a key task or summary).
- *Project SSI Tornado Graph*. The schedule sensitivity index of a task is calculated by multiplying its criticality index by the ratio of its variance against the variance of the project (or key task).
- *Project Criticality Tornado Graph*. The criticality index of a task is the proportion of the iterations in which it is critical.

P6 projects can be opened in Primavera Risk Analysis.   Primavera Risk Analysis illustrates these features with a housing project tutorial. Views of a P6 based plan of a water supply project with features to convert deterministic duration to triangular distribution along with the project completion schedule sensitivity is given in **Figures Q.4** and **Q.5**:

Figure Q.4

Project Input on Screen
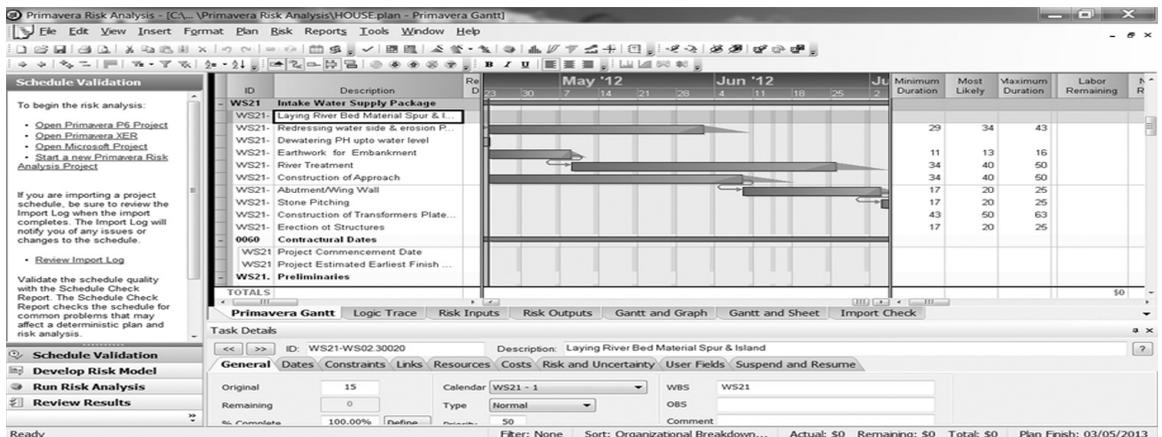
Figure Q.5

Project Monitoring Output Showing Time Schedule Status and Completion Trends
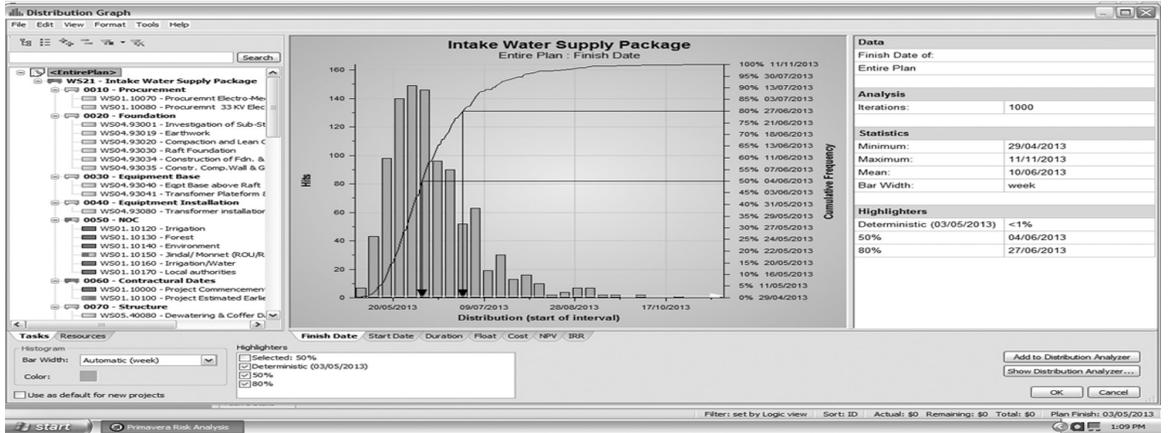
Note: For more information about Oracle's Primavera Risk Analysis, please visit: http//:www.oracle.com.

Project Management Information System

Project management aims to achieve the project's objectives within specified constraints. Project implementation encounters unpredictable problems. It needs an effective information system to keep it on the track. An information system is a set of inter-related components that capture, process, store, and distribute information in order to support decision making in an organisation. Management Information System (MIS) broadly includes all the managerial functions/systems of an organisation that contribute to achievement of objectives. Advances in information technology have revolutionised information management systems of modern projects.

Integrated MIS of a corporate/project includes inter-related systems, such as Work-Scope Management System, Time Management System, Resources Management System, Cost Management System, Finance Management System, Procurement Management System, Quality Management System, HRD Management System, Communication Management System, Client-Relation Management System, Public Relations Management System, Supply-Chain Management System, and Risk Management System. These systems are inter-related. As modern projects increase in size and complexity, the need to obtain data and deliver information to functional managers in a corporate and to authorised persons, in real time, is assuming far greater importance than it did a few decades ago.

Project Management Information System (PMIS) in a project generally covers the information related to planning and controlling of scope, time, resources, and cost of a project. PMIS coverage can be extended to cover the needs of functional managers of a project organisation and enterprise departments. In multi-project environment of a corporate, it can be designated as Enterprise Projects Management Information System (EPMIS).

Project Management Information System involves developing the PMIS framework, establishing baselines and standards for monitoring performance,economically capturing and processing monitored planning data during implementation,retrieving information from monitored

data,communicating this information to the right person to facilitate decision-making, storing the relevant information documents, protecting information, and managing the information resources. Management of PMIS involves the processes tabulated below:

Processes	Tools and Techniques	Outcome
Project Data Management	Data structuring and codification Baseline creation	Work packages, activities, resources and cost code dictionaries, baselines.
Information Retrieval using PM Software	PM Software Support All-in ERP Solutionsw	Monitored information, what if analysis, remedial options
Information Communication	PMIS reporting, feedback and Information Communication tools	Decisions to control changes/Information Communication
Documents Management	Document storage and updating methodology	Updated planning documents

The project management tools and techniques related to the baseline planning and performance control of scope, time, resources, and costs are covered in respective chapters in the book. The concept of Project Management Office (PMO) has added a new dimension to the management of PMIS.The PMO emerging concept is outlined towards the end of this chapter. This chapter is divided into the following sections:

1. Importance of Information in Project Context
2. PMIS Framework
3. PMIS Data Structuring , Codification, Reporting and Trend Analysis
4. Information Retrieval using PM Software
5. Information Communication Using IT Applications
6. Project Documents Management
7. Role of PMO in Multi-Project Environments
8. Factors Influencing PMIS Success

Applications of a typical project management software are outlined in **Appendix F** of **Chapter 6**. Cloud computing is covered in **Appendix R**. This chapter includes some illustrations from APEX project of Primavera Project Planner software and these illustrations are reproduced with kind per mission of Oracle USA (www.oracle.com).

❑ 18.1   IMPORTANCE OF INFORMATION IN PROJECT CONTEXT

18.1.1   Understanding Information in Project Context

Often the terms data, documents, and information are used synonymously. In the context of project data represents specific facts. There are three types of data: basic data, performance data and documented data. Basic data covers the project's initial activity database and the project baseline plans. Performance data represents the actual outcome of the planned activity on a given date (data date).

The performance data is processed by the project monitoring centre to analyse its variances from the basic data and standard documents to retrieve information required for decision-making. Documented data termed as 'documents' include standard data, such as approved design and drawings, contract documents, purchase orders etc., that are referred for business transactions. Information is extracted from the data to help managers in performing their functions efficiently and effectively.

The term 'information' means different things in different contexts. In the context of project, information is what the human mind has perceived to be of use for making decisions after studying/analysing the basic data, performance data, and/or documents. Information plays an important role in binding the building blocks of modern multi-division, multi-location and multi-national organisations.Information Systems can improve timely execution of the project, control resources' productivity, and reduce cost overruns.

18.1.2   Information Needs in PMIS

Traditionally Management Information System (MIS) role was limited to generating reports, however, today it is playing a strategic role. As modern projects are increasing in size and complexity, the need to obtain data and deliver information to functional managers in the corporate and authorised persons at the project site, in real time, is assuming far greater importance than it did a few decades ago. The information is needed by stakeholders, project and functional managers, and operating levels within a project for making decisions to control changes from the planned path.

An efficient PMIS generates information that helps to:

- Improve the productivity and economise the employment of resources;
- Enable understanding of time and cost behavior;
- Provide early warning signals of ensuing dangers;
- Update resources planning and costing norms;
- Prevent pilferages and frauds;
- Assist in formulating bonus/incentive schemes for motivating people;
- The quality information generated eliminates sudden shocks;
- Bring in transparency;
- Organise data according to the need;
- Provide speedy solutions to what-if queries; and
- Keep concerned managers informed of the 'need-to-know' information.

Information Quality Characteristics.   The information which is to be used must fulfil the following characteristics:

1. **Accuracy**. The quality of information shows the degree of accuracy with which the reality is represented. It must be reliable, error-free, precise, clear, consistent, and understandable by those who need it. Incorrect information can mislead managers.

2. **Timely**. The information, when needed, is useful if it is available on time.
3. **Economical**. The information should be economical enough to support the situation that warrants a decision.
4. **Adequate**. The information should be adequate. Excess information costs money and causes overload, while, insufficient information can frustrate the decision-maker's efforts.
5. **Usable**. The information furnished to a manager should be relevant to his area of responsibility and what he needs to know.
6. **Comprehensive**. The information should be presented in a comprehensive manner by using appropriate graphs and highlighting the critical factors.

18.1.3 Sources of Information

The information is needed by stakeholders, project and functional managers, and operating levels, within a project for making decisions to control changes from the planned path. PMIS derives information from the project's internal and external sources related to the project.

The internal sources cover the updated baseline plans, formal and informal reports by the project team, visits to the site and study of the standard documents, and performance data reports from the project interrelated subsystems, such as Work-Scope Management System, Time Management System, Resources Management System, Costs Management System, Finance Management System, Quality Management System, HRD Management System, Communication Management System, Client-Relations Management System, Public-Relations Management System, Supply-Chain Management System, and Risk Management System. In project environments these systems are inter-related.

The external sources of information that assist the information manager in managing project information are vast and diverse in nature. The external sources of information include but are not limited to the following:

- Government policy, Research publications, Commercial journals, Industry magazines, Academic journals, Websites;
- Contractors, government and public sector agencies, contracting and construction related publications, Construction cost indices;
- Architect and Engineering associates, Consultants, Professional bodies; and
- Builders and Consultant Associations, Web enabled electronic libraries, National building codes and construction specifications.

18.1.4 Information Technology Applications in PMIS

Information technology is widely used for processing data electronically and communicating information in all its forms including text data, graphics, images, voice, chat, documentation storage,

and combinations of these. The main benefits of IT are speedy manipulation of data and real-time information distribution to distant geographical locations. Without automated processing, it is almost impossible to quickly monitor the project status and implication of variations from the planned program.

Information technology applications started from 1970 with the basic entry-level office automation and presently goes up to highly advanced project-specific systems. Basic technology covers office operation automation, productivity tools and document management software. Medium and high-level technology includes architecture, engineering design, and project data processing for decision-making. Most of the applications that involve medium and high-level technology can be run on personal computers.Advanced technology applications are rarely used in the project management environment. Application software can be classified as shown in **Table 18.1**:

Table 18.1

Typical Application Software Classification

Technology Classification	Typical Software Applications
Low	Word processing, Spread sheets, Accounting, Finance, Database
Medium	Estimating, Scheduling, Simple designs, Specifications, Quantity take-off, Survey data processing, Computer Aided Design Drafting (CADD), Automated Information retrieval using project management software, Communication and documentation management
High	ERP systems, Expert systems, Decision support system, Risk management software. Artificial intelligence, 3D modelling computer-integrated building design, Robots
Advanced	Business Intelligence software , 3-D Drawing management system, GPS system, Portfolio management systems

The above classification is not rigid. Project management system tools are outlined in **Sections 18.4** and **18.5** of this chapter.

The advancement in Information Technology, computer hardware and software technology undergoes improvements with the passage of time. The current bunch of software tools vary in functionality and scope. The recent developments in computer hardware and software have made virtually all-in-one ERP software functionally feasible.With the advancement in Information Technology (IT) and with a view to understand the different types of available software tools, the application software for managing project's information can be broadly categorised as under:

1. **Office management tools**. The primary purpose of office information tools is to facilitate speedy communication within the project, between the project, and corporate offices. An office information system includes word processor, spread sheet, data access, and presentation software. Some office information tools also include office documentation management system, message handling system, tele-conferencing system and office support system.

2. **Project management software tools**. These software include Oracle-Primavera products and Microsoft Project.There are many other project management software solutions available. Commonly used project management software can create plans, speed up reporting, monitor performance, organise data, evaluate what-if analysis implications, and up-to-date planning documents.These facilities are covered in **Section 18.4**.

3. **All-in-all modular ERP systems**. ERP integrates all department and functions throughout an organisation into a single IT system (or integrated set of IT systems) so that authorised persons can take decisions by viewing information spread throughout the enterprise for all business operations. An ERP system provides a method for effective planning and controlling of all enterprise resources. ERP is outlined in **Section 18.4**.

4. **Hosted web-based tools**. Anyone with authorisation can access the website using inter net. The main advantage is that it is comparatively cheaper than acquiring a system. It also guarantees tracking and providing solutions using hosted software facilities.

5. **Companion tools**. These tools supplement the standalone project management tools to make up for functional deficiencies. Examples of such tools or software are Microsoft Excel and Risk Management. In particular, spreadsheet software, such as Microsoft Excel provides formulae and other facilities that are widely used in PMIS for:
   - Numbers' manipulation: Enables development and updating of financial statement, forecasting of resources etc.;
   - Creating charts, graphs and diagrams.
   - Organising data; and
   - Solving formulae and problems like time-cost trade-off, resources allocation,cash flow, updating financial status and earned value analysis.

❑ 18.2   PMIS FRAMEWORK

18.2.1   Information Management Policy

Traditionally, Management Information System (MIS) role was limited to generating reports, however, today it is playing the strategic role. As modern projects increase in size and complexity, the need to obtain data and deliver information to functional managers in the corporate and authorised persons at project site, in real time, is assuming far greater importance than it did a few decades ago.

The focus of the policy for managing project information is to develop information architecture to manage PMIS by creating, capturing, and processing data to derive information; to distribute it to the concerned persons, and finally record it in suitably designed documents.

A suitably designed and effectively implemented PMIS policy is essential for improving managerial efficiency and effectiveness in projects. The information management policy generally includes PMIS function, PMIS architecture, PMIS structure, and the responsibility of the project team and information manager in implementing PMIS.

18.2.2   PMIS Functions

PMIS is an integrated user-machine system that provides information to support operations, management, and decision-making functions, which are related to planning and controlling of the project's objectives. Its main functions are:

1. To develop PMIS strategy in consultation with the project team and stakeholders and communicate this to all concerned authorities after getting approval by the project manager.
2. To establish an initial database with data structure codes and baselines.
3. To set standards and baselines against which the progress and costs can be measured and compared. These standards and baselines include the project time schedules, the project control budgets, material schedules, labour schedules, productivity standards, quality assurance, and control methodology.
4. To organise efficient means of measuring, collecting, verifying, and quantifying the data that reflect performance with respect to time, cost, resources, and quality.
5. To manage the means of converting data from operations into information.
6. To report the correct and necessary information in a form, which can be best interpreted by management and should be at a level that is most appropriate for the individual managers or supervisors who will eventually use it.
7. To provide management 'exception reports' that highlight critical factors.
8. To communicate the information on time for consideration and decision-making for remedial corrective action to the concerned authorities, and to protect it from unauthorised access.
9. To identify and acquire data from both internal as well as external services (i.e. suppliers, client, consultants, project team members, etc.).
10. To create and store digitise documents, drawings, baselines, and database.

   Notes:
   a. PMIS is a broad concept rather than a rigid system. Its design varies with the nature and type of the project.
   b. PMIS deals with structured information that is systematically and routinely collected. It does not include informal and unstructured information, for example, information gathered at the bridge table or on a golf course.
   c. PMIS provides formal information for planning and controlling decisions at various levels. Unless specifically instructed, it does not include information to be provided to statutory bodies and other outside agencies.

18.2.3   PMIS Architectural Components

PMIS architectural components consist of hardware and software and its infrastructure comprises of data structure, related documents, operators, procedures, and OBS. The data management and documents needed are covered in subsequent sections of this chapter.

Hardware. The term hardware covers the entire electronic and electro-mechanical equipments that are used in the computerised data processing system. Peripherals are referred to externally connected devices of the computer, such as input devices, storage disks, and output devices. The choice of hardware is based on type of selected software (see **Figure 18.1**).

Figure 18.1

Hardware Components of a Computerised System
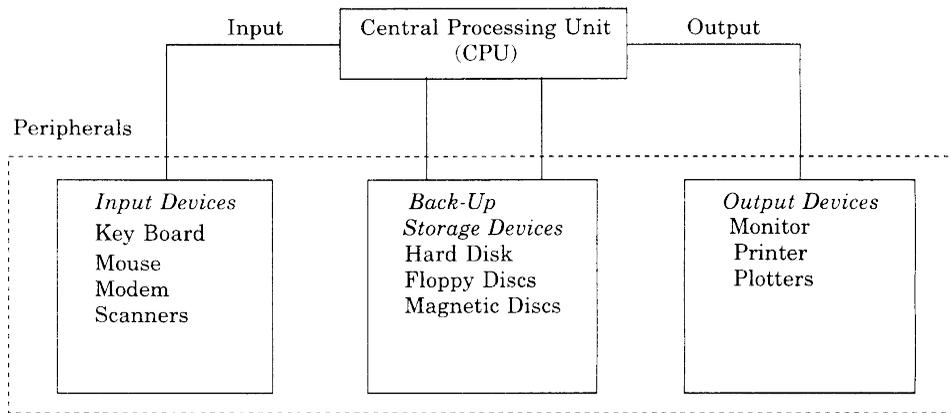
Software. The computer hardware needs proper instructions in order to perform specified operations. All these operating procedures and instructions in case of computerised system are grouped under the heading 'software'.Software are defined as the product of highly skilled brains. They undergo constant improvements similar to the development of micro-electronic technology of the computers. The choice of hardware is based on the selected software. In other words, it is the software that decides the type of hardware required.

Typical software needed for perform ing managerial functions include:

Project Team Function	Some examples of software needs
Planning/Information Manager	Project Management Software
Technical Manager	Computer-aided Design and Drafting Software
Cost and Finance Manager(s)	Cost and Finance Management Software Standard Schedule of rates
Contract Manager	Special Purpose Quantity Surveying and Contract Management Software
Materials Manager	Inventory Management and Stores Accounting Packages

Plant and Equipment Manager	Equipment Management Software
HRD Manager	Personnel Management Software
Executives	Time keeping and productivity analysis software

ERP software can link the information requirements of all the department and functional heads in a Construction Corporate. It is outlined in **Section 18.4** of this chapter.

18.2.4   PMIS Infrastructure Components

Operators. These include computer operators, systems analysts, programmers, data preparation personnel, information systems management, data administrators, etc. In particular, the in-house monitor who heads the PMIS can be assigned the following functions:

- Formulating policies and procedures for data-processing systems;
- Creating baseline plans and databases as required;
- Standardising formats for management control reports;
- Establishing planning and performance measurement standards;
- Mobilising, allocating, and monitoring resources for various tasks;
- Collecting and collating reported data including activities in progress; employment of man-power, equipment and materials; and evaluating resources productivity;
- Monitoring actual achievements against planned targets, focussing attention on deviations for effective management decisions and actions, and re-planning when necessary in order to achieve specified performance objectives;
- Tracking variances from productivity standards and feedback of the monitored productivity information to site executives;
- Updating resource productivity norms, planning data and unit rates of work, and rendering assistance to site executives on construction planning and formulating. This is usually done on a monthly basis;
- Receiving and acquiring relevant information from appropriate sources (e.g. suppliers, clients, and consultants);
- Protecting information from unauthorised access and change;
- Maintaining technical records, project history, data bank, publications and project library; and
- Setting up a project control room displaying vital and up-to-date information.

Procedure.   Standing operating procedures, such as manual or instruction booklet are the regulatory framework that stipulate series of actions for handling the specified situations. Standing operating procedures in a project manual may include the following:

- Project organisation and management responsibility;

- Projects proposal approval policy;
- Project quality management system;
- Administration of contracts;
- Design and project development;
- Document control;
- Purchasing and storage and retracing losses of supplies and services;
- Packing, dispatching, storage and handling of materials;
- Testing, inspection and test equipment calibration;
- Non-conformity to quality system and rework;
- Product quality records;
- Internal quality audits;
- Personnel training;
- Statistical data records;
- Safety and health and environment protection; and
- Statutory requirements and compliance responsibility.

18.2.5   PMIS Configuration and Responsibilities

Organisation Breakdown Structure (OBS) is defined as the hierarchy of an organisation's key persons who perform activities that produces the deliverables. These are people who implement the project and account for its performance. The key persons are referred by their designation or names. To quote an Exhibit, the organisation structure of 2000 Housing Units is given in **Exhibit 1.1** and its responsibility centres are shown in **Exhibit 1.2**.

PMIS can be viewed as a group of information sub-systems. Each organisational responsibility centres in a project can be viewed as a sub-system. These sub-systems are highly inter-dependent and interactive. **Figure 18.2** shows the outline of the internal progress control system of a Housing Units Project.

PMIS responsibilities.   PMIS is not a one-man show and needs the co-operation of team members and the backing of stakeholders. The nature of co-operation and responsibilities can vary from project to project. Typical responsibilities of project team members and PMIS are outlined in **Table 18.2**:

❑ 18.3   PROJECT DATA STRUCTURING, CODIFICATION, PERFORMANCE REPORTING AND TREND ANALYSIS

18.3.1   Project Data Structure and Codification

A major turnkey construction project has two organisations at the site, i.e. the client's organisation and the contractor's organisation. Each one of these has architects, designers, estimators, planners,

Figure 18.2

PMIS Internal Configuration
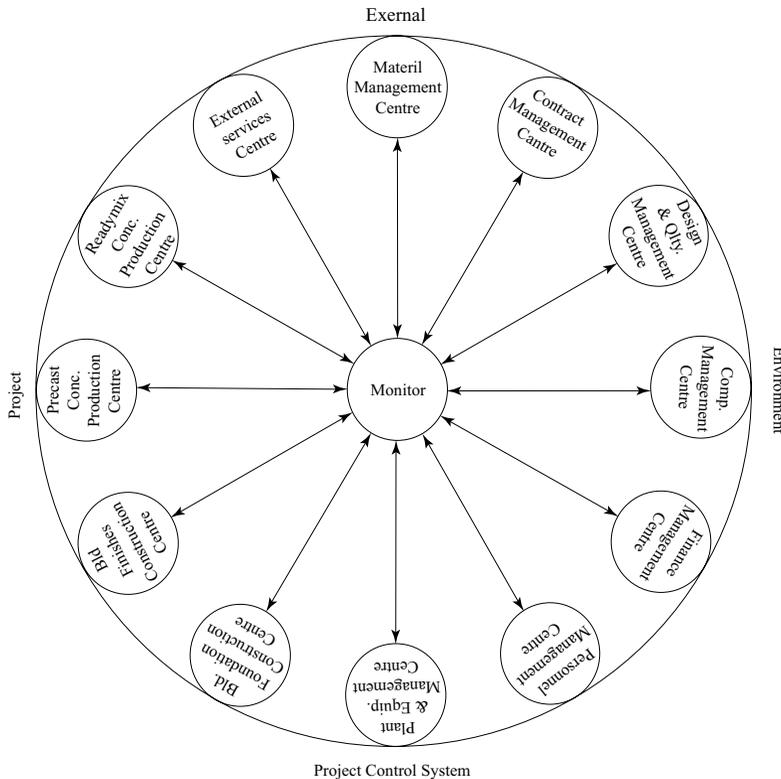
accountants, and construction engineers, with inter-related functions for managing the project. In addition, the contractor's organisation (which manages the execution of project work) also has managers in charge of planning materials, plant and equipment, personnel, and finance. In a major project, data is generated and processed by many agencies/organisations/stakeholders. This includes the client, architects, designers, estimators, PMO, contractors, vendors, bankers, functional managers, executives, etc. If, left to them, each manager/functional head will have to develop his own data structure (and codes) to identify, sort, and process data and this may lead to confusion and duplication of efforts.

Example: **Table 18.3** shows the two-character alphabetic component of the significant code adopted for representing various types of buildings in the 2000 Housing Units Project.

A suitably designed unique activity identification code can assist process of project management to identify each work package/activity with some attributes for the purpose of organising data. The

Table 18.2

Typical Responsibilities of PMIS and Project Team Members

Processes/Position	Project Team Member Responsibilities	PMIS Responsibilities
Integrated Project Plan Development	• Study design and drawings and reconcile discrepancies • Prepare work related method statements • Assist PMIS in preparation of the plan and its base document • Provide appropriate area specific inputs	• Identify constraints and assumptions affecting the project • Involve stakeholders in preparation of project plan • Finalise the project plan and communicate to the persons
Integrated Project Plan Execution	• Complete work assigned • Assess performance of work packages against the plan • Access earned value against the plan • Keeps the PMIS informed and up to date about progress • Attend and participate status review meeting	• Review performance and provide feedback to the project team • Provide authorisation to team members to access information, as appropriate • Communicates with stakeholders • and concerning relative information • Issue PMIS reports • Conduct status review meetings
Integrated Change Control	Identify required changes in scope and analyses them for technical approval	• Setup an integrated change control system for the project • Evaluate implication of changes to the project and incorporates approved changes into a revised project baseline • Issue revised project plans resulting from approved changes • Identify, analyse and compile historical records and lessons learned as and when they occur

first two characters of a sub-project, when prefixed in the activity number (ID) indicate that the activity belongs to the sub-project group, see **Table 18.4**.

Note: A code is termed as significant if it can be easily understood by applying certain sets of simple rules to each of its component. For example, if a code is based on mnemonic features, it can help the user to memorise the code. Further, accounting becomes simple if the code includes numerical digits. Generally, significant codes consist of two or more alphanumeric components. For example, **BW 013**, representing activity block work of building number 13, can be termed as significant code where, BW = Block work and 013 = Building numbers.

18.3.2 Project Data Codification Approach

A project organisation handles large varieties of data. This data includes activities, resources, costs, and documents. A simple approach to describe these items is to assign suitable names to them. This

<div align="center">

Table 18.3

2000 Housing Units Project: Types of Buildings and Utilities Codes

</div>

Code	Nature of Work	Code	Nature of Work
HU	Housing unit	WT	Water tank
PS	Primary school	WP	Water pump house
HS	High school	SW	Sewage pump house
KG	KG school	BH	Boiler house
NR	Nursery	EL	Electrical services
SO	Social centre	UW	Unfiltered water supply
SC	Shopping complex	FW	Filtered water supply intake
SS	Sub-shopping complex	FD	Filtered water distribution
YC	Youth centre	HW	Hot water supply
HC	Health centre	SD	Sewage drainage system
BP	Baath party	SW	Sewage collection and pumping
PL	Police station		system
HM	Hammam	ST	Storm water drain system
MQ	Mosque	SM	Storm water collection and pumping
SP	Swimming pool		system
PF	Post office	GS	Gas supply
RS	Receiving station	LS	Landscaping
SB	Sub-station	RD	Road walkways and pathways

process may result in several different names being assigned to each item by different persons handling the same item. It is therefore, essential to develop a code to identify each frequently occurring item. Codes enable easy identification, data classification, and quick retrieval of data.

The data code is built up by using alphabets, numerals, symbols, or a combination of these. These codes abbreviate data and expressions in natural languages into some set of pre-determined string of characters by using alphabets, numerals, symbols, or a combination of these. These are not the arithmetic numbers or functions that are used for making calculations.

Short-length data code reduces storage space and costs. Each code is unique. In fact, an organised control of a major project is not possible without the proper codification of project data. Data codes are developed primarily to serve a four-fold purpose:

- To identify each activity with its database;
- To aid in the organisation of data in levels from the very detailed to the broadest levels;
- To enable the processing, sorting, extraction, and organisation of information required at various levels of management and functional units; and

Table 18.4

Housing Project Base Preparation Work Package

ID	Activities
RBFD013B11	Layout for excavation
RBFD013B12	Excavation with machine
RBFD013B13	Base preparation
RBFD013B14	Anti-termite at base
RBFD013B15	Polythene sheeting
RBFD013B16	Shuttering for blinding
RBFD013B17	Placing concrete M-100

Note:
RBFD represents the Residential Building Foundation;
013 is the Building Module Location Number;
B represents the Base Preparation Work Package; and
11 to 17 are the serial number of activities

- To computerise the data processing system.

Code types. There is no end to the demand for the codification of data from the various departments within a project. But unnecessary codes can create confusion and may defeat the very purpose for which they are designed. Some of the aspects, which may need codification, are listed below:

- Activity, work package, sub-group and group identification;
- Bill of quantities;
- Cost accounting system;
- Drawings and specifications;
- Equipment identification;
- Finance accounting system;
- General and administrative accounts;
- Head office expenses;
- Jobs, sub contracts;
- Labour categories;
- Material types;
- Numbering activities, areas, building locations, etc.; and
- Overhead Categories: Projects codes; and Management reserve.

Codification effectiveness. For a codification system to be effective, it should fulfil the following requirements and should be:

- Comprehensive enough to interface the varying needs of all concerned;
- Concise enough not to get lost in voluminous elaborations;
- Flexible enough to accommodate new items;
- Significant enough to be easily recognised, e.g. abbreviations of the letters to be codified;
- Logical enough so that its composition follows a systematic building up approach;
- Simple enough to be understood by a non-technical person;
- Compatible enough to be programmed for computer application;
- Short enough to fit into the character space earmarked in the software; and
- Publicised enough so as not to become a mere paper exercise.

It is not possible to have a perfect codification system for a given project. However, a suitably designed workable codification system is indispensable.

18.3.3   Project Planning Data Codes

In the construction projects , there are number of labelling systems in vogue. Some of these are designed for specific applications. These systems include universal decimal classification system (UDC), Construction Specification Institute System (CSI system of USA), Computer based Project Management and Costing System (CBC), and Construction index/Samarbetskommitten for Byggnadsfragor system (CI/SfB). These are useful for codifying systems but no two projects are similar in nature. Invariably, codes are customised in PMIS of construction projects.

Project planning data can be broadly codified into the following categories:
- Project/sub-project codes;
- WBS codes dictionary;
- Activity identification codes;
- Activity related data codes dictionary;
- Resources codes dictionary; and
- Cost accounting codes dictionary

Generally, WBS is used as a base for developing the project codification structure. The list of codes used for a specified purpose is referred to as 'codes dictionary'. Data in a project is structured into various WBS levels right down to the activities. Project structures and codes are illustrated with examples from the APEX Project.

18.3.4   APEX Project Planning Data Codes

In a corporate, the projects can be coded by numbers, country regions, industry, nature of work, or a combination of these, but, in case of a large-sized project (also called as project group), each project can be divided into sub-projects. A sub-project, such as the Residential Building Complex of 2000 Apartments Housing Project described in Chapter 3, thus becomes a part of the main project (i.e.

project group). Such sub-projects are managed and controlled independently but the changes in a sub-project are reflected in its parent project group. The list of project/sub-project codes becomes the project/sub-project codes dictionary. In case of multi-projects, being handled by a corporate, the project codes are listed in the enterprise projects codes dictionary.

Take the case of APEX car manufacturers, who are expanding and modernising their plant. Three areas of the project are organised into sub-projects, viz. Robotics Automated Production System; New Conveyor System and Office Building Expansion Construction. The Work Breakdown Structure (WBS) for APEX divides the project into its three major components or tasks groups—Automation System (AS), Conveyor System (CS) and Building Addition (BA).

APEX Project Scope and its Sub-projects Codes. APEX Project scope can be subdivided into Task Groups (deliverables) **Table 18.5** lists the scope of the APEX project:

Table 18.5

Showing APEX Project Scope

Tasks Groups	Scope of Work
Robotics automated production system (AS)	Designing, installing and testing an automated production
New conveyor system (CS)	Designing and installing a new conveyor system to move the automobiles through the various manufacturing stages
Office building additions (BA)	Office building expansion construction

WBS is baseline for structuring data. The WBS of a project is a most valuable tool for structuring work-related data. It enables the project manager to manage the project successfully. It forms the basis for defining the work scope , identifying activities, structuring organisation, assigning responsibilities, estimating costs, codifying systems, organising data, and analysing the sources of risks. These applications of WBS are covered in **Appendix C** of **Chapter 3**.

In a project, data is structured into various WBS levels right down to the activities. The database of activities form the basis for developing a project plan. Each assigned activity has responsibility, phases, departments, costs, resources, calendars, etc. to organise data, simplify data management, and ensure consistency between the project codification structures.

Project WBS structure enables speedy data organisation and summarisation of data in the various WBS levels with associated responsibility, phases, departments, costs, resources, calendars, etc. These are explained in the next section.

APEX Work Packages Codes of Conveyor System. The WBS of a project forms the basis for defining the work scope, identifying activities, structuring the organisation, assigning responsibilities, estimating costs, codifying systems, organising data, and analysing the sources of risks. These applications of WBS are covered in Chapter 3.

The Work Breakdown Structure (WBS) for APEX divides the project into three major components—Automation System, Conveyor System, and Building Addition; and further these components are sub-divided into discrete work packages as shown in **Table 18.6**:

Table 18.6

APEX Work Breakdown Structure (WBS) Codes of Conveyor System

Activity ID	Description	Manager Responsible Code	Phases Code	Department Code
CS305	Start-up and De bug System	JN	INSTL	CON
CS310	Review and Approve Design	MF	DESGN	ENG
CS311	Start Conveyor Installation	JN	INSTL	ISD
CS315	Site Preparation	JN	INSTL	ISD
CS400	Prepare and Solicit Bids for Conveyors	KL	PROCR	PCH
CS410	Review Bid for Conveyors	KL	PROCR	PCH
CS420	Award of Contract	KL	PROCR	PCH
CS430	Prepare Drawings for Conveyors	MF	DESGN	ENG
CS440	Review and Approve Drawings for Conveyors	MF	DESGN	ENG
CS450	Fabricate and Deliver Conveyors	KL	PROCR	PCH
CS700	Install Conveyor 211	JN	INSTL	ISD
CS710	Install Conveyor 212	JN	INSTL	ISD
CS720	Install Conveyor 213	JN	INSTL	ISD
CS730	Install Conveyor 214	JN	INSTL	ISD
CS740	Field Piping	JN	INSTL	ISD
CS750	Field Wiring	JN	INSTL	ISD
CS760	Field Painting	JN	INSTL	ISD
CS770	Operation Manual	KL	INSTL	ISD
CS800	Conveyor System Complete	JN	INSTL	ISD

APEX Activity Identification Code.   Activity Identification (ID) Code of an activity refers to a unique code that identifies the activity. A suitably designed unique activity identification code can assist process of project management to identify each work package/activity with some attributes for the purpose of organising data. The first two characters of a sub-project, when prefixed in the activity number (ID) indicate that the activity belongs to the sub-project group, see **Table 18.4**.

Figure 18.3

APEX MODERNISATION PROJECT: WORK BREAKDOWN STRUCTURE OUTLINE

AUTO SYSTEM (AS)
1.1 Design Engineering
1.2 System Engineering
1.3 Software Engineering
1.4 Training
(Total 45 activities)

OFFICE BUILDING
(BA)
(Total 71 activities)

CONVEYOR SYSTEM
(CS)
2.1 System Design and
Engineering
2.2 Field Operation
2.3 Training
(Total 20 activities)

3.1 Design
and Eng.

3.2 Foundation

3.3
Structure

3.4 Mech./Elect
works

3.5 External
Works

3.6 Interior
Finishes

Some project management software, such as MSP 2007, automatically assign activity ID in serial order, whereas, in case of Primavera software, activity ID's are assigned in a methodical manner that enables organisation of project data in a way as illustrated in **Appendix F**. Readers should refer to the manuals of project management software for codify activity IDs.

APEX Activity Data Codes Dictionary.   Each activity in a project has certain characteristics/attributes associated with it. These include the persons responsible, the department concerned, phases of development, location of activity, and so on. Activity data codes are used to organise data in the required manner, for example, grouping activities under specific categories, summarising activities, customising bar color and pattern, and creating reports and graphics. Building the activity codes dictionary may require entering as much as a four character code title for each characteristic/attribute associated with the activity. Each code title can be further divided into an unlimited number of values. Extract from Activity Data Code Dictionary of Apex Project is given in **Table 18.6**

APEX Resource Codes Dictionary.   The physical resources needed for work to be performed in a project include manpower, material, and machinery. Manpower can be split into various categories, such as management, administrative staff, technical staff, site supervisors, equipment operators and drivers, and skilled and unskilled labour. The number of materials required may run into hundreds. The needed equipment may be of different types and sizes. The variety of workers, materials, and equipment are enumerated in **Chapter 7–9**. These have to be categorised into manageable groups/teams in order to identify, account for, and monitor each item of resource. Generally, while developing a database, the resources are limited to major items of manpower, materials, and equipment.

APEX Project Example. APEX requires several resources, including design engineers, automation system engineers, programmers, construction workers, and management personnel. P3 can assign an unlimited number of resources per activity using upto eight characters to identify a resource code. A part of the resources input data is tabulated below:

The resources are assigned to activities, where P3 can produce an appropriate plan of resources for each category and organise their allocation. P3 has the facility to sort, summarise, and filter specific resources, for the purpose of allocation and analysis.

APEX Cost Accounting Codes.

A cost accountant is responsible for the cost management information system of the project and is accountable for all the costs. These costs include the standard or budgeted costs, actual costs, and future costs. Normally, his database is the available work package. He develops costs for each work package. Cost account codes are developed by interlinking work packages with its responsibilities. Cost Account Heads of Accounts Codes are listed in **Table 18.8**; If necessary, these can be modify suitably confirming to the applicable software code.

For example, in cost account '11233 Robot Control Installation':

- First character 1-indicates the project name (APEX);
- Second character digit 1-indicates Robotics Automatic system;
- Third character 2-represents hardware package;
- Fourth character 3-represents system controller; and
- Fifth character 3-indicates Director of Hardware Engineering.

The cost accountant compares the actual costs incurred for a work package with the standard or budgeted costs. In order to identify, account, and control different types of costs, it is necessary to label the essential characteristics of each cost, so as to build up its composite structure. These can be done by suitably post-fixing the cost category code with the cost accounts heads.

The cost accountant can split production cost of each work package into the following elemental costs:

Cost Categories Code in Each Head of Accounts

S. No.	Accounts sub-head	Code
1	Direct labour costs	L
2	Direct materials costs	M
3	Direct equipment costs	E
4	Subcontract costs	S
5	Other Direct costs	O
6	Indirect costs	I

7	Subcontract costs	S
8	Production costs	P
9	Value of work done	V
10	Budgeted Cost	B

In projects using project management software, such as P3 or Excel, each activity costs can be broken down into cost categories in the activity code dictionary.

Table 18.7

Resources Codification Example

Resources ID (8 characters)	Description	Units	Rate/unit ($)
ACCTS	Accounts Manager	Hr	16.00
DESENG	Design Engineer	Hr	30.00
ELEV	Elevator Installer	Hr	40.00
EXCAVTR	Excavator	Hr	21.50
FLDENG	Field Engineer	Hr	25.00
FNISHR	Finisher	Hr	24.00
HVACTEC	HVAC Technician	Hr	15.75
IRWK	Iron Worker	Hr	32.50
LABOUR	Labour	Hr	20.00
SYSTENG	System Engineer	Hr	25.00

18.3.5   Site Performance Data Reporting and Analysis

Site reporting objectives.   The project integrated plan indicates the path to be followed in order to achieve the project objectives. It defines the parameters that should be controlled and establishes the baseline for measuring performance during execution. Project control during the implementation phase implies reporting performance by the responsibility centres and monitoring performance changes from the planned path (preferably using project management software solutions) of all the objective related processes.

Nature and frequency of performance data reports.   In a project, each control responsibility centre, generally transmits data to PMIS, while accounting performance. For example, the nature and frequency reports in 2000 Housing Units Project are listed in the Exhibit 13.2. Most of the project management software solutions by default, have a format of specimen reports. In fact, each project should customise the nature and frequency of these reports, according to the requirement. Guidelines for designing performance data reports are covered in Chapter 13.

Table 18.8

Cost Account Heads of Accounts

Cost Account	Account Title
11101	Automatic System Design
11211	Temperature Control Equipment—Design
11213	Temperature Control Equipment—Install
11221	Robot Control—Design
11223	Robot Control—Install
11231	System Controller—Design
11233	System Controller—Install
11314	Software Processor
11415	Automation System Training and Manuals
12101	Conveyor System Design
12213	Conveyor System Installation
12223	Conveyor System Testing
12311	Conveyors—Design
12312	Conveyors
12325	Conveyor System Operation Manuals
13106	Building Addition Design
13206	Foundation and Site Work (Civil)
13306	Building Structure
13416	Elevator
13426	HVAC
13436	Plumbing/Piping/Electrical
13516	Brick
13526	Roof
13536	Doors/Windows
13616	Floors/Carpeting
13626	Plumbing and Lighting Fixtures
13636	Carpentry
13646	Painting

PMIS Monthly Performance Report. PMIS is an organised method that systematically provides information of the past, present, and future trends for making decisions to achieve specified objectives. PMIS communication includes a variety of oral and written reports that are suitably designed to provide information to parent corporates, stakeholders, management team, and executives.

The corporate management or the board of directors are primarily concerned with the progress, profitability, cash flow, and capital investment that are needed for achieving the project's objectives. The project report outlines the present performance along with future trends and targets. It focuses on the actual and potential deviations from the planned path where possible remedial actions are recommended to overcome adverse situations.

The report, thus, enables the top management to exercise an effective control over all aspects of the project.

The contents of a monthly PMIS report to its parent corporate may include the following:

1. **Project particulars**. This shows the report title, the number and date of the report, the project name, the code number, location, client's details, and the site address.
2. **Project objectives status**. This outlines the overall performance, including a summary of information relating to project billing, work progress, budget status, and expected completion date.
3. **Project parameters' performance**. The performance of parameters to be reported depends upon the corporate policy. The selected parameters can vary from few in number such as status, work progress, and budget status to a detailed report on the performance against the targets of each responsibility centre.
4. **Project resources mobilisation forecasts.** This outlines the near-future resource requirements at the site for achieving the planned targets. These include:

   - Site staff status and the forecast of requirements;
   - Workers status and the forecast of requirements;
   - Material sample approval status and the scheduled approvals;
   - Major materials procurement status and the scheduled requirements; and
   - Equipment status and the induction schedule for the balance required

5. **Gist of important site meetings.** These include meetings with the client's representatives, sub-contractors, suppliers, and other connected agencies. It is in addition to the recorded minutes of the meetings which are submitted to the top management.
6. **Concluding remarks.** The concluding paragraph of the report summarises the overall performance and highlights the actions, which are requested by the top management.

Example. The monthly report of an MNC included the following headings (contents omitted) is given below:

1. Management Summary Report

1. 1. Contract Budget vs PM Budgeted Cost Status
1.2. Contract Value Summary
1.3. Monthly Project Contract Value Summary

1.4. Progress Billing Status

1.5. Project Staff Strength previous month end

1.6. Monthly Highlights

2. Financial & Commercial Reports

2.1. Cost to Complete: Materials

2.2. Cost to Complete: Subcontracts

2.3. Cost to Complete: Departmental Labour

2.4. Cost to Complete: Direct Plant & Equipment

2.5. Cost to Complete: Preliminaries

2.6. Cash-flow Report

2.7. Payment Schedule

2.8. Contract Amendments Record

3. Project Management Reports

3.1. Areas of Concern and Plan of Action

3.2. Plant and Tool at Site

3.3. Sub-Contractor Status

4. General Report

4.1. Design and Drawing Status

4.2. Material Approval Status

4.3. Non-Conformance Report

4.4. Health, Safety and Environment Report

5. Progress Photographs

The project management information report must be concise and meaningful. It should indicate the variances from the planned targets with reasons. It should also restrict the report to essentials making the report exception oriented by focusing attention on its critical areas. Its content should contain statistics, graphs, charts, and other details that have visual appeal. As far as possible, narration should be kept to the minimum. It should highlight potential bottlenecks and aspects that require immediate action at the top management level. Moreover, it should also avoid duplication of effort by designing the reporting format to conform to the site reports, computer software requirements, and codification system.

   The project management information report does not include classified information such as contract disputes, controversial issues and financial matters. These are dealt with separately.

Performance variance analysis.   The primary purpose of the performance reports is to highlight the baseline changes. The performance analysis process commences after the appropriate

performance data is received by the monitor through progress reports, personal visits, and discussions. The performance variance from the baseline generates information, which helps to analyse the causes of deviations from the planned or budgeted approach.

For example:

$$\text{Work quantity variance} = \text{Planned work quantity} - \text{Actual work quantity}$$
$$\text{Activity duration variance} = \text{Planned activity duration} - \text{Actual activity duration}$$
$$\text{Production cost variance} = \text{Standard production cost} - \text{Actual production cost}$$

Variance, when evaluated, can either be zero, positive or negative:

$$\text{Variance} \geq 0, \text{Favourable (F)}$$
$$\text{Variance} < 0, \text{Unfavourable (U)}$$

A variance is said to be controllable, if it is associated with the operational efficiency, such as the responsibility of an executive or the performance of a work center. The variance due to the wastage of concreting material is known as controllable variance. On the other hand, the causes of variance that are beyond the control of the management, such as increase in labour wages due to labour legislation are known as uncontrollable variances. Cost Variance analysis generally follows the approach that is been covered in **Chapter 15**.

Trends forecasting.   Performance variance analysis reveals the extent and causes of variances. On the other hand, performance efficiency (or index) determines how efficiently the task was done.

$$\text{Performance efficiency} = \frac{\text{Planned (or budgeted) cost of performed}}{\text{Actual cost of work performed}}$$

$$>1, \text{performance better than planned}$$
$$=1, \text{performance equal to planned}$$
$$<1, \text{performance less than equal}$$

Performance efficiency is a trend indicator. Therefore, a forecast for a given work can be made after taking considering observed efficiency, past experience, and the achievable skill level. Understanding some of the techniques and concepts, which are given below, can help in producing a realistic forecast of future performance. There are no hard and fast rules to determine which technique will be used or when and where it will be used. A brief description of techniques is as follows:

a. **Time and cost overruns forecasting techniques**. Network analysis, and line-of-balance technique. Project time and cost overrun analysis is covered in **Chapter 15**.
b. **Statistical analysis and operations research methods**. Data analysis, forecasting, regression analysis, statistical control charts (similar to statistical quality control) and analytical decision-making techniques.

c. **Management accounting technique**. Cost accounting, cost control, working capital management, cost-benefit analysis, break-even analysis, and performance audit.

d. **Management concepts**. Management principles, behavioural science, personnel management, materials management, plant management, finance management, contract management, and quality management.

Planning, executing, accounting, monitoring, information communication, decision-making, and re-planning, are continuous controlling processes and goes on till the project is completed. The modes of information communication by the monitor to the project teams and the top management are covered in **Section 5** of this chapter.

❑ 18.4   INFORMATION RETRIEVAL USING PROJECT MANAGEMENT SOFTWARE

18.4.1   Project Management Software

The market is flooded with project management software. A search for project management software on the worldwide web displays or lists down hundreds of software solutions related to project management. Oracle-Primavera, products including Primavera P6 Enterprise Project Portfolio Management (P6 EPPM), Primavera Professional Project Management (P6), Primavera Project Planner (P3), Primavera SureTrak, and many others (visit: http://www.oracle.com/primavera). Other project management software includes MS Project Management, Project Scheduler, Artemis Prestige, and Power Project. Each software manufacturer claims to be the best for functions provided by them. MS Project is a widely used computerised project management tool, but, Primavera products are most sophisticated. MS Excel is a useful tool for work-sheet analysis. Readers are advised to visit the website of the concerned software companies. It may be noted that there is no single project management software that meets all the needs for all the projects. The ultra high-tech sophisticated software is also difficult to implement, learn, and support. The application of the project management software depends upon the level of use, types of uses, level of training received by the respondents, and adequacy of the software. The latest project management packages have following features:

- Plan Model and Schedule Development facilities;
- Project resources and cost planning and monitoring facilities;
- Project schedule monitoring facilities;
- Project data organising and filtering (sorting) facilities;
- Reporting and graphics facilities;
- Editing Facilities, Utilities and Web-enabled Applications;
- Creating many different layouts. A layout shows the view of the processed data; and
- Data and documents management facilities.

The capabilities of project management software are illustrated in **Appendix F**, with layouts from Primavera (P3 and P3e). For more information on the following Oracle's Primavera products, you can visit: http://www.oracle.com/primavera.

Oracle's Primavera Enterprise Project Management Products.
Primavera P6 Enterprise Project Portfolio Management: Release 7.0.
Primavera P6 Professional Project Management
Primavera Portfolio Management
Primavera Inspire for SAP
Primavera Contract Management
Primavera Risk Analysis
Primavera Earned Value Management
Primavera Contractor
Primavera SureTrak
Primavera P3 Project Planner
Primavera Integration Solutions

Notes:
1. Spreadsheet software like Excel are useful for quick data processing operations, such as planning, scheduling, reporting, and monitoring of design, cost etc.
2. Cloud computing has revolutionised IT functioning, see **Appendix R**.

18.4.2   All-in-all Enterprise Resources Planning Solutions

"ERP system integrates all departments and functions throughout an organisation into a single IT system (or integrated set of IT systems), so that authorised persons can make decisions by viewing enterprise-wide information of all business operations. An ERP system provides a method for effective planning and controlling for all resources of the enterprise."

Development of information systems that is based on ERP (see Figure 18.4) enables companies to implement integrated processes across various department and/or functions. ERP systems are used as strategic tool and fall under following two categories:

- Inter Organisational Systems; and
- Business Networking systems

ERP seeks to standardise including integrate diverse operations and information flows in a corporate, by synergising its resources through information technology and converting the same into meaningful/useful information with the help of information system.

Since the start of this century, the market ERP systems has witnessed considerable growth. ERP companies include SAP AG, PeopleSoft, Baan, and Remco. Oracle has recently acquired PeopleSoft and Primavera.

Figure 18.4

Enterprise Resources Planning System

Core ERP Component
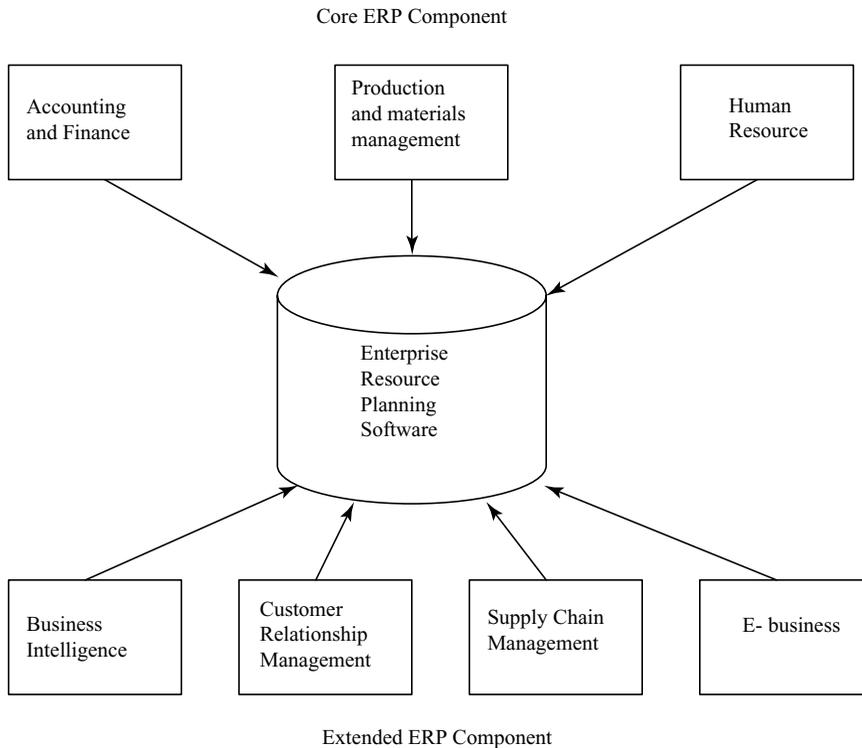
18.4.3 **Common ERP Application Benefits and Prerequisites in PMIS**

ERP Benefits

a. *Integrates financial information*. It shows the overall performance of the organisation.
b. *Integrate work progress and procurement information*. It is easier to coordinate in a single system.
c. *Standardise and speed up information processes*. It saves time, speeds up information flow, and reduces manpower.
d. *Reduce inventory*. It streamlines procurement processes and delivery of resources.
e. *Standardise human resources information*. It provides a unifying method for tracking employees' time as well as communicating HRD benefits and services.

ERP Pre-requisites

a. *Systems requirements*. Depending upon the system specifications, in addition to core components, it may need several extended components to meet specific requirements.

b. *Re-engineering organisation*. It is necessary to match software systems.
c. *Installation and commissioning time*. It may vary from some months to even more than an year.
d. *Installation and operating costs*. It may vary from lakhs to crores.
e. *Reliability of meeting stipulated system requirement*. Its procurement and implementation needs thorough study as past experience shows that most of these have time and cost overruns and a few are even discarded after starting off. Further software acquirement and hardware account for a small fraction of the total ownership cost includes system integration and change management.

❑ 18.5 INFORMATION COMMUNICATION USING IT APPLICATIONS

18.5.1 Communication Process

The process of communication has seven main elements. These are sender, message, receiver, feedback, channel, situation or setting, and barrier of noise or interference. Communication begins with the sender. The sender encodes the message, which represents an idea or feeling in words or signs, and transmits this message to the receiver. The receiver decodes or interprets the message according to his/her perception of the message. Perception or interpretation of the same message may vary between people depending upon their experience, attitudes, belief, skills, or expectations. Feedback is defined as the receiver's response to the sender's message. Message is sent via organisation communication channels, which can be horizontal or vertical, using a conversation, letter, telephone call, radio, or television program. A situation is a setting within which a message is encoded and decoded. In a given situation, the same message can have a different meaning depending upon emotions and reactions to ideas. Thus, the received message is not necessarily the same as that sent by the initiator because of some barrier, such as noise or interference, which creates a communication gap. The causes of communication barriers include inappropriate choice of words, channel, message, receiver, and/or sender effort.

Successful communication sends or transmits the ideas, values, and attitudes, to others through three different forms of communication—verbal, nonverbal, and graphic. Verbal communication makes use of words to communicate. Some ways of communicating verbally, are orally spoken words in briefings, telephone conversations, interviews, public speaking, or may also be written words in the form of text. Non-verbal communication covers the communication sent by means other than words. Face-to-face contact, facial expressions, body movement, posture and dress are some of the examples of non-verbal communication. Graphic communication visually represents the ideas, relationships, shapes, diagrams, and lines. Generally, a typical message may contain one or more components of various forms of communication.

The communication skill which PMIS uses to communicate determines its effectiveness. The two main types of communications, it performs are, transmitting PMIS reports to the top management and others concerned and communicating performance feedback to the project teams.

18.5.2   Feedback Communication to Project Team

Feedback reveals what was achieved, what was targeted for accomplishment, what was the extent of deviations in the performance, what caused these deviations, and what are the remedial courses of possible action.

Feedback can be communicated in many ways. It can be transmitted either orally or in writing, such as briefings during regular planning meetings, or in form of brief feedback reports. As far as possible, writing of lengthy minutes and notes should be avoided.

It is important that feedback should be given on time, as delayed feedback may not serve its purpose, e.g. it is useless informing a site engineer a week after the completion of an activity that the productivity was 20% lower than the standard rate. Timely feedback creates prompt awareness and enables the initiation of timely remedial actions.

In some projects, contractors do not encourage feedback. As they believe it can reveal business secrets and jeopardise the security of their information. These contractors may wish to conceal their estimates and performance figures for bidding in future works to support their financial claims. In such cases, the remedy lies not in withholding the feedback, but in suitably codifying the feedback. This codification can be achieved by giving performance feedback data in the form of percentages of standards instead of actual numbers by graphical representations of performance, or by other suitable methods.

It may be noted that the monitor diagnoses the deviations and formulates suggested remedial options, but, cannot automatically implement these deviations and remedial options. The site executives are responsible for processing the work as per the project plan and correcting deviations from the planned path.

18.5.3   Communication Tools

Telecommunications and information technology are resulting in reduced communication barriers. Managers can have relatively faster access to the databases, whether, centralised or distributed. Not only the access to information is fast, but, also everyone can obtain up-to-date data, as well as, post their own inputs for others without causing delay.

Information can be shared among various groups working at the same geographical site by LAN (Local Area Network). The data may be maintained on a central computer (Server) and can be accessed and updated by users from different terminals (Clients). Terminals at different sites may be connected to the LAN through an e-mail. This makes the information accessible and easy to update from remote locations.

LANs at different sites may be connected with each other through WANs (Wide Area Networks). In such systems, part of the information may be held centrally and some part may be handled only at the LAN site. Internet, a large area network with an open distribution system offers facilities for disseminating information over geographically dispersed areas.

18.5.4 Virtual Reality Tools for Information Interchange

Most computer systems create a real-time experience of visual, audio, and animated effects. Visual reality represents a powerful tool within the real environment. The pre-requisite for data exchange in real time is the digitalisation of data and is done by using appropriate software. The project management software, when fed with data, produces real-time results with the click of the mouse. For example, a computer can simulate what-if solutions using project management software quickly. Other examples are Computer Aided Design (CAD), drawings of data exchange, and bar code for inventory management. Data and video conference are the other means of information exchange.

Three tools for communicating bundled data are being used extensively. These are the Internet, Intranet, and Extranet. Documents are sent by e-mail to others at their e-mail IDs. It provides the facility to reply by return mail address. Through e-mail, a message can reach the recipient in very less time. Unlike telephone conversations, the communication taking place is recorded. The recipient can respond to received e-mails at this convenience. E-mails can also transmit documents as an attachment to messages.

18.5.5 World Wide Web (www)

In this, information is generally organised in form of HTML pages. Information in HTML is easily and directly accessible to anyone having a computer and internet connection. The basic idea of www is to merge the techniques of computer networking and hypertext into an easy to use global information system. With electronic documents, these cross-references can be linked globally within the world wide web environment.

❑ 18.6 PROJECT DOCUMENTS MANAGEMENT

18.6.1 Project Document Management System

A document is a set of information pertaining to a topic that is handled as a unit which is stored and structured for human comprehension. The document management system includes creation, storage, organisation, transmission, retrieval, manipulation, update, and eventual disposition of documents to fulfill an organisational purpose. An electronic document system uses information technologies to manage the documents. For example, Microsoft SharePoint Document & Workflow Management System can handle document management capabilities that enable the following:

- Store, organise, and locate documents;
- Ensure the consistency of documents by versioning, check in, and check out;
- Manage metadata for documents for easy search and retrieval;
- Help secure documents from unauthorised access or use through authentication and authorisation;
- Enterprise level integration through LDAP authentication; and
- Automate business processes (workflows) for how documents are handled.

Project data structure, codification and reporting is covered in Section 18.3. The brief coverage in this Section is limited to:

- Nature of Project Documents
- Recording Performance
- Documents Tracking

18.6.2 Nature of Project Documents

In most projects, documentation forms an essential element in the production process. In case of engineering design and consultancy firms, for example, this is the only output of their process. The management of project quality assurance documentation avoids extensive re-working and ensures effective quality control of the project.

The project documents provided by the monitor/planning chief can be set up at each project centre to hold the following up-to-date records for ready reference:

- Contract documents, including the terms and conditions, drawings, specifications, bill of quantities and activity-wise costs and sale prices;
- Project models, layout pictures, tabulated scope and progress of work statements and photographs depicting the work progress;
- Project plans and connected charts, networks and planning assumptions, including the productivity standards;
- Statistics of various reports and returns handled in the project and pictorial displays;
- Records of minutes of all meetings, conferences, policies and important correspondence;
- Control charts showing the progress of work, the mobilisation status of resources, contract cost status and the 'S' curve forecasts; and
- Updated unit rates and resource cost planning data.

It is ideal to have a project control room at the project office, where all updated data and information are displayed at regular intervals on charts as well as on models.

18.6.3 Recording Performance

Performance recording involves documenting the facts about actual progress of the goals/targets/ activities/resource utilisation, using established procedures or specified devices and presenting

these facts in a concise and comprehensive form for analysis. The performance measured is documented scientifically.

It is necessary to record the work progress, resource employment, and other progress related matters, and then compare it with the planned progress. The types of documents required can vary from client to client and from project to project. Some of the commonly used and jointly maintained contractual documents for recording performance related matters are as follows:

- Work schedule and work programs;
- Work diary;
- Stage passing register;
- Work deviations order register;
- Work measurement books;
- Work progress report;
- Materials sample approval register;
- Materials inspection registers;
- Major equipment employment register;
- Equipment instruments calibration certificates;
- Equipment performance report;
- Contract cost status; and
- Minutes of site meetings.

Usually, it is also the practice to record daily events such as weather, activities in progress, manpower engaged, major materials received, equipment deployed, comments of visitors, and important events of the day in the works diary.

Recording the performance of the contractor at the project site can be divided into two groups, i.e. recording in contractual documents and recording in the contractor's own accounting documents. Contractual documents are primarily used by the client and the contractor to record performance related data in accordance with the contract stipulation. But these are not sufficient for the contractor to control his time, resources, and cost objectives. In addition to the contract stipulation document, the contractor may design his own accounting system for the project parameters. Generally, his functional head maintains records centrally, but the physical performance data, originates from the respective responsibility centres.

Project Management Software can store baseline plans. It enables storing and constant updating of period performance records, resources, and accounting transactions. It can generate reports showing the status of men, materials, equipment, cost, and finance. The benefits of document management include:

- Time savings for information suppliers and users by automating the reporting processes;
- More and updated information for managers leading on to better decisions;
- Improve company and project processes; and
- Support strategic evaluation of a company.

18.6.4   Documents Tracking

It may be noted that project documents are frequently updated/revised/modified. It is therefore essential to keep proper records of these amendments. The concept behind the document tracking and control system is two-fold. First, to keep the document updated and second, to provide the access of entire project team to all pertinent project documentation. In addition to providing a means of assistance to the team and improving communication, the system provides standardisation of project documents, a well-defined workflow process, and an organised real-time database of the project documents.

Construction project management involves groups of people representing different disciplines from project managers, contract managers, and division managers, to subcontractors, architects, engineers, suppliers, and owners—all trying to collaborate on a multitude of issues and changes while, juggling multiple documents and contracts. Controlling the construction project plan, budget, forecast costs, and deliverables is vital to the success of projects as well to the future of the business. Electronic document management concentrates on creation, revision, distribution, storage, and retrieval throughout and beyond the project lifecycle.

❑ 18.7   ROLE OF PROJECT MANAGEMENT OFFICE (PMO) IN MULTI-PROJECTS ENVIRONMENTS

A PMO according to PMBOK Guide, an American National Standard ANSI/PMI 99-001-2008, "is an organisational body or entity that is been assigned various responsibilities related to the centralised and co-ordinated management of projects under its domain." It implies that PMO is established in multi-project environments or in corporate office. Its primary function is to provide project management support. It can be managed entirely with organisational persons or consultant staff or a combination of both with defined tasks. The outsourced component of the project management office becomes the Project Management Consultant (PMC) Office.

In a small or medium size project, a monitor/planning manager/project control engineer with some staff, can manage the PMIS. In a large/mega size project or multi-projects environment, a Project Management Office (PMO) can be established to provide project management support. Issues involved in outsourcing entire or part of PMO establishment (called PMC) of a corporate or a project to a consulting unit include:

1. What are the implications of outsourcing processing of information system-advantages, dangers and pitfalls?
2. What are the different kinds of responsibilities in PMO that can be outsourced?
3. How can PMO manage communication and interpersonal relationship with the project manager(s)?
4. What are some of the factors that can negatively affect the successful implementation of a PMO?

5. Will the corporate like to share their business related information with the consultant units of a PMO?

Due to the secret nature of construction, corporate business-intelligence, outsource of information resource in a construction project is still a debatable issue. Some organisations prefer not to outsource PMIS or EPMIS departments to consultants as it can result into purposeless policing, misrepresenting facts, and adding unnecessary overhead costs. Another option is to have an in-house PMIS and EPMIS, and hire a third party consultant to have project management performance audit from time to time instead of installing an outsourced PMO set up.

❑ 18.8   FACTORS INFLUENCING PMIS SUCCESS

PMIS Performance Model.   There can be numerous factors that influence the performance of PMIS in construction projects but main factors that contribute to the success are information expectations, system installation quality, system outcome, impact on project organisation, and benefits of PMIS success. The major influencing factors are inter-dependent and can be modelled in **Figure 18.5** as below:

Figure 18.5
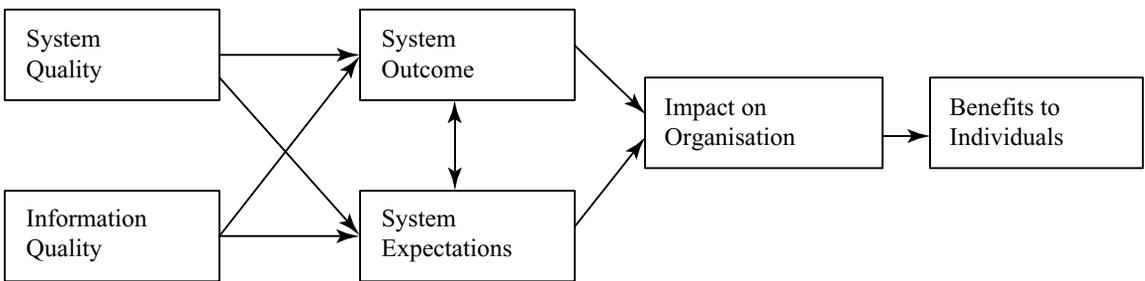
Systems expectations. PMIS is assigned certain functions by the project management. It develops/approves and monitors project baselines at specified frequency and communicates appropriate information at various levels.

Expectations are the perceived usefulness of the system. People do not know what they want until they get what they do not want. It is therefore necessary that the functional requirements of the computerised system be crystallised in the initial stage prior to purchasing the system. The first step here is to define user's requirements. It dictates the IT specifications.

System installation quality. It implies installation of the system that meets user's requirements for information system. The quality information means having in-place and necessary infrastructure to produce accurate, timely, economical, adequate, useable, and comprehensive information. The infrastructure includes IT hardware, system analysts and operators, standing operating

procedures, and documents, such as contract agreement, WBS and OBS, project plans, and planning and monitoring policy. The IT hardware requires training of all participants to perform their role in PMIS, creating PMIS benefit awareness, ensuring information quality feedback from construction sites, and communicating appropriate information at various levels. It needs co-operation of project team and stakeholders in addition to support of top management.

Procurement, installation, and performance of the computerised system is not trouble-free. The system procurement poses problems and the installation too has teething troubles. However, the following guidelines can minimise these difficulties:

1. Acquiring a computerised system needs extra effort and is a time-consuming process. It should be treated as a project in itself.
2. Success of the system depends upon the suppliers' support. Therefore, the supplier should be chosen after a thorough scrutiny.
3. Scrutinise the system carefully before purchasing. The end result should not be a case where the patient dies but the operation is successful.
4. The initial 90% of system installation costs are incurred in the early stages of installation but it is the last 10% of installation and commissioning that becomes tricky and time-consuming.
5. Do not give up if the system does not function properly in the beginning. If anything can go wrong, it will. There will be problems and a few problems are not the same as failure.
6. Job training on the installed system will instil confidence. A detailed study of manuals may reveal extra facilities which the trainee may not have thought of earlier.

The system must be tested thoroughly after the installation by running it with known inputs and outputs. This will lead to confidence in the system and may reveal previous unnoticed exceptions in the system.

All those who are concerned must be kept informed about the progress of computerisation at regular intervals, before, during, and after the system is installed. This will save time in answering frequent enquiries.

System outcome. Actual outcome shows the usefulness of the system. It shows how far the system has met perceived expectations. Experts reveal that in most of the projects, the outcome falls short of system expectations. Management of information is not trouble-free. The increase in size and complexity of projects, the accelerating rate of change, and risks involved in managing these have contributed to the inadequacy of the present information management effort. The major information related problems existing in most projects could include situations where:

- Information is not easily accessible;
- Information is misinterpreted;
- Information overload is common;
- Some people conceal information; and
- There is a resistance to change.

Information delays are a mismatch of information/data as a result of unsystematic data reporting by functional managers and executives that can adversely affect information outcome, leading to information overload, information losses, misunderstanding of PMIS role, poor co-ordination, and poor quality of information provided. However, it is crucial for a project to establish PMIS since without proper and timely information it may be doomed to failure.

Impact on an organisation.   The interaction between the systems expectations and systems outcome leads to behavioral awareness. This behavioral awareness results in positive organisation culture or it produces adverse reaction towards PMIS performance. The culture of information sharing and awareness of the usefulness of PMIS are symbols of transparency in the organisation. It is the top management support that enhances PMIS effectiveness and team work. It is the general opinion of the experts that PMIS failures occur from the application of irrational approach by the top management and lack of their support.

Benefits of PMIS success.   There are several benefits expected from a PMIS. The benefits commonly attributed to a well conceived PMIS are outlined below:

1. It prevents sudden shocks as concerned authorities are kept informed of any deviations from the planned process/baselines.
2. It provides remedial options and assists executives in making decisions towards achieving objectives and/or modifying the existing course of action. Project management software, in particular, enables transparency in the decision-making process.
3. It makes use of the emerging IT to generate information and present solutions. However, PMIS is not a substitute for human skills.
4. It integrates monitored documents and stores information for current and future use. In case of any deviation, the integration highlights implication of changes in the system and the remedial measures to counter adverse effects due to these changes..
5. It improves overall performance and management control by improving efficiency, reducing paperwork, standardising processes, generating reports quickly, facilitates faster communication of information, thereby, reducing information accessibility time, avoids duplication of effort and errors in information communication, and improves overall co-ordination.
6. It generates time, resources, costs, quality, risk planning data for use in future projects and increases competitiveness in the market share.
7. It improves service to the stakeholders, enabling interaction between them, and enhances communication by providing an electronic link between client, contractors, vendors, suppliers in sincere companies and financial institutions.
8. In successful PMIS environments all participants gain experience in PMIS. Training and educating can add to the skill development of the participants. PMIS is not a one-man show and needs the co-operation of team members, the backing of stakeholders, and the support of top managementfor the successful implementation of the information system.

APPENDIX R

Cloud Computing

❏ R.1   WHAT IS CLOUD COMPUTING?

Traditionally, each corporate office has its own IT System with own servers, application software and development infrastructure. These are procured and managed internally. It involves capital investment, updating and operating costs. These are designed to cope with the peak level of load. Corporates are now adopting cloud computing to cut capital investment, reduce manning costs, and time consuming updating systems.

According to USA National Institute of Standards Technology (NIST), cloud computing is a model for computing that offers on-demand network access to a shared pool of configurable computing resources (such as networks, servers, storage, applications and services). It can be rapidly provisioned and released with minimum management effort or service provider interaction.

In simple words, Cloud computing service provider builds an invisible IT environment to manage customer data. These services include software applications, data processing platform and on-line IT infrastructure to build internet applications. The Cloud is generally located geographically far away from the user. The application and data are processed on the cloud by the cloud computing server and not on the user local machine.

Essential characteristics of Cloud Computing are that it provides:

- *On-demand self-service*. A consumer can unilaterally provision and release computing capabilities, such as server time and network storage, as needed, automatically without requiring human interaction with each service provider.
- *Broad network access*. Capabilities are available over the network and can be accessed through a variety of platform such as desktops, mobile phones, tablets, laptops, and workstations that promote use by heterogeneous thin or thick client platforms.
- *Resource pooling*. The provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to consumer demand. Examples of resources include processing, storage memory and network bandwidth.
- *Rapid elasticity*. Capabilities can be elastically provisioned and released, commensurate with demand at any time.
- *Measured and monitored service*. Resource usage can be measured, monitored, controlled, and reported providing transparency for both the provider and the consumer of service.

- *Low ongoing costs and flexibility in payments*. Most standard operation and maintenance operations are handled by the Cloud provider. It reduces receiver time and maintenance costs. Further, there is a flexibility in payment mechanism such as 'pay per use', this helps cut capital investment, and reduce operating and maintenance costs.

There are multiple cloud providers in the market and they are increasing by the day. However, Amazon, IBM, Microsoft, Google and Oracle are one of the top cloud providers today. These can be accessed on internet for further information

❑ R.2   CLOUD COMPUTING SERVICES AND DELIVERY MODELS

Service Models.   In 2009, the National Institute of Standards and Technology, USA Department of Commerce (www.nist.cloudcomputing), defined Cloud Computing in SP800-145, as the three service delivery models:

- **Software as a Service in Cloud computing (SaaS)**. The SaaS service providers offer special selections of software running on their infrastructure. SaaS is also known as software on demand (software as needed). Analyst now consider SaaS to be one of the several subsets of the cloud computing market.
- **Platform as a Service in Cloud computing (PaaS)**. The PaaS users develop their own software applications within a software environment that belongs to and is maintained by a service provider.
- **Infrastructure as a Service in Cloud computing (IaaS)**. Cloud computing offers virtualsystems to access computer hardware resources such as networks and storage. With IaaS, users freely create their own virtual computer cluster and are therefore responsible for the selection, installation, operation and functioning of their own software.

Delivery Models.   National Institute of Standards and Technology has classified four delivery models:

- **Public Cloud Computing**. It provides abstracted access to IT infrastructure for the general public via the internet. Public Cloud Computing service providers allow their customers to rent IT infrastructure on a flexible basis for the actual utilisation or consumption (pay-as-you-go), without having to invest capital in computing and data center infrastructure.
- **Private Cloud Computing**. It provides abstracted access to IT infrastructure within the organisation (e.g. agency, company, and club).
- **Community Cloud Computing**. It provides abstracted access to IT infrastructure for a smaller group of users who are mostly distributed locally and share the costs (for example, universities, business/corporate with similar interests, research communities).
- **Hybrid Cloud Computing**. It offers access to abstracted combined IT infrastructure in the areas of public clouds and private clouds, to meet the needs of users.

❑ R.3   CLOUD ECONOMICS: AN OVERVIEW

R.3.1   Cloud Computing System Components

Globally, IT industry is handling ever increasing terabytes of information. The sheer volume of data processed shows as to why managing and analysing it is a challenge. With so much data being used in so many ways, the IT infrastructure has to constantly accommodate fluctuating demands in processing and storage. This challenge has created large size data centres in the clouds. Consolidated or pooled resources enable better utilisation of resources. Pooling resources in a cloud model allows for greater flexibility and faster innovation for dynamic business demands.

Cloud computing system is the common base that plays an important part in the provider's service delivery capabilities and the customer's performance. The key components of the cloud computing system are:

- **Hardware**. It comprises of servers, networking equipment, storage and the various interconnect between them. It is the foundation of the system.
- **Software**. This layer primarily consists of the software that manage the underlying hardware-operating system, Net OS, Storage management etc.
- **Core services**. For example, virtualisation, antivirus, etc.
- Product/services/apps portfolio. Apps and services that will touch the end user.

Cloud Computing System

R.3.2   Customer's Cloud Computing Economics

There are several reasons that are driving IT organisations to consider moving data centers to the cloud. IT organisations can become more effective at meeting the challenge of business requirements faster than ever before—all the while maintaining or preferably cutting costs. The Cloud facilitates enhanced capacity to cater for all workloads. In a fast growing business, they can build new solutions for each of those initiatives much faster without affecting overall performance.

At the mega corporate level, IT organisations are migrating to the cloud or becoming more cloud-like by setting up private clouds with customised and standardised database platform

services with superior capabilities and efficient performance at a lower cost. It is illustrated with a typical example reproduced below:

Calculating In-house Versus Cloud Initial Costs

CapEx Line Item	In-house			Cloud Based		
Unit of Measure	Quantity	Unit Cost	Totals	Quantity	Unit Cost	Totals
Servers	Number	100	150,000	15,000,000	0	0	0
Routers	Number	10	5,000	50,000	0	0	0
Switches	Number	10	2,500	25,000	0	0	0
Cabling	Meter	1,000	250	250,000	0	0	0
Storage (Primary)	Terabyte	100	25,000	2,500,000	0	0	0
Storage (Backup)	Terabyte	700	25,000	17,500,000	0	0	0
OS Licenses	Number	100	1,000	100,000	0	0	0
MW Licenses	Number	25	2,500	62,500	0	0	0
DB Licenses	Number	25	5,000	125,000	0	0	0
ERP/ App Licenses	Number	100	1,000	100,000	0	0	0
Migration	Number	0	0	0	1	100,000	100,000
Staff	CTC/ Month	10	1000,000	1,000,000	3	100,000	300,000
Real estate	Sq. ft.	5,000	250	1,250,000	0	0	0
Totals				**37,962,500**			**400,000**

Source: Cloud Computing, Authors: Arvind Doss and Rajeev Nanda, Publisher McGraw-Hill Education, India.

Calculating Recurring OpEx Costs

OpEX Line Item	In-house			Cloud Based		
Unit of Measure	Quantity	Unit Cost	Totals	Quantity	Unit Cost	Totals
Hardware maintenance	Percentage of cost	15	22,500	337,500	0	0	0

Software maintenance	Percentage of cost	25	2,500	62,500	0	0	0
Leased line	Cost per month	2	25,000	50,000	2	25,000	50,000
Electricity	Cost per month	1	100,00	100,000	1	25,000	25,000
Staff	CTC per month	10	100,00	1,000,000	3	100,000	300,000
Computing power	Per hour usage	0	0	0	25,000	10	250,000
Storage usage	Per GB usage	0	0	0	1,000	5	5,000
Real estate	Sq. ft.	5,000	250	1,250,000	2,000	250	500,000
Totals				**2,800,000**			**1,130,000**

Source: Cloud Computing, Authors Arvind Doss and Rajeev Nanda, Publisher McGraw-Hill Education, India.

Before choosing a cloud vendor, the service receiver by examining the vendor's offer must understand as to what it guarantees and what it does not. Amazon, for example maintains a 'Service Health Dashboard' that shows current and historical uptime status of its various services.

R.3.3 Service Provider's Cloud Computing Economics

Cloud computing has large potential and huge market. But the setting up of a cloud service and its management by a service provider is a complex process. Its economies depend upon the demand and supply, power supply usage effectiveness, infrastructure labour costs, the security and reliability of data processed, and buying power of processing and storage equipment.

To quote an example about demand and supply, the overall cost incurred by the supplier/vendor is determined not only by capacity but also efficient utilisation of capacity. There is a utilisation variability factor, which includes users' access pattern such as degree of randomness and time of the day for service. Variability peak and trough in service provisioning results in uneven resource utilisation, administrative problems and cost performance. Many suppliers are faced with the problem of keeping the lights on idle resources.

The vendors charge for the cloud services depends on the nature of service. SaaS Vendors are selling software on a pay-as-you-go, as-need basis, preventing the kind of lock-in inherent in long-term licensing deals for on-premises software. Amazon's Elastic Compute Cloud charges on the basis of per-hour usage of virtualised server capacity. Each vendor has a pricing model depending upon the service offered and the underlying costs.

❑ R.4 ADVANTAGES AND MAIN PROBLEMS IN CLOUD COMPUTING

R.4.1 Advantages

The majority of the user companies see improvement in one or more areas of their IT department after adopting the cloud computing services:

- Cost savings. Anticipated cost reduction in cloud delivery system as compared with IT— could be as high as 40%–50%. The savings can result from less of hardware, minimising waste, lower energy consumption and reduced manpower support.
- Low capital cost. Firms can avoid upfront capital investment in infrastructure. Firms can provide new services to customers speedily as they do not have to wait for installation of new equipment.
- High performance. It increased data center efficiency and resources utilisation. Cloud computing has built in efficiency since it eliminates the need to go through the server provisioning team.
- Flexibility. The user can hold enough capacity to handle normal IT load and in the case of strongly fluctuating demand for a short duration, the user can take support of cloud computing service provider to meet the actual demand thus reducing their investment costs.

A November 2011 study by tech consulting firm CSC found that 93% of the 3,645 global IT decision-makers surveyed, reported better performance in their IT departments after adopting the cloud. Those improvements resulted in:

- Increased data center efficiency and use (52%)
- Lower operating costs (47%)
- Reduced waste and lower energy consumption (64%)

In the United States alone, organisations will save an estimated US$12.3 million a year in energy costs by 2020 by moving to the cloud, as per a 2011 report by the Carbon Disclosure Project.

R.4.2 Main Problems

Putting corporate performance data into the hands of cloud computing service provider can save money for a construction corporate but it raises host of data security issues.

Data safety in the cloud is not a trivial concern. Online storage vendors have lost data and were unable to recover it for the customers. There is always danger that sensitive data could fall into wrong hands. Before signing up with any cloud vendor, customers should demand information about data security practices, scrutinize SLAs and make sure they have the ability to encrypt data both in transit and at rest.

The basic problem is protection of access to the application data in the Cloud during transfer between local client and remote server. As part of any cloud computing plan, the user must under-

stand as to where the data is, who has the access to it, does it need to be codified, how it is being backed-up and what is the recovery plan in case of a disaster like that of Amazon Web Services.

The three biggest cloud computing security concerns among European IT decision-makers, as mentioned in 2011 report by the Carbon Disclosure Project are:

- Preventing data loss (71%)
- Preventing outages (64%)
- Keeping security up-to-date (58%)

❑ R.5   FUTURE TRENDS IN CLOUD COMPUTING SERVICES

Looking to cut costs and increase efficiencies, organisations are moving more and more data to remote servers. According to a recent survey of IT Solution for the 21st Century Survey:

- 61% of organisations are currently using, evaluating or planning to use cloud computing based services within the next year; and
- Organisations are set to increase their adoption of cloud computing over the next decade from 10% to 70% of the IT spend.

However, cloud computing data security and risk of cyber threats are of real concern to the corporate using cloud computing service. The corporate concern is to know the server's data recovery plan in case of a disaster, how long is the provider in business, the place where is its data centre is located and how often the server conducts penetration test by a third party on the level of safety and security of the data. The corporate executives and key persons should always be on guard to prevent vital data security. In today's business life, IT investors are no longer asking whether they should embrace the cloud but are focusing on how to use it for cost-savings and on how and when to divest their IT operations.

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Index

Note. Index lists page numbers of definition or meaning of Project Management specific Key Words or Expressions. It excludes commonly understood words and construction technology related terms. Abbreviations are reflected against words or expressions, where applicable.

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