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SCHOOL OF BUILDING AND ENVIRONMENT

DEPARTMENT OF ARCHITECTURE

SAR 1611 – PROJECT MANAGEMENT

I. Unit 1 – Traditional Approach & Network analysis

II. Unit 2 – Probability Analysis

III. Unit 3 – Project cost and resource allocation

IV. Unit 4 – Software applications

UNIT – I – TRADITIONAL APPROACH & NETWORK ANALYSIS

I. Introduction

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.

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. The studies reveal that most of the construction projects face time and cost overruns mostly due to management failures.

Project management by definition is as below

"**Project management is the application of processes, methods, knowledge, skills and experience to achieve the project objectives**"

"**Project management is the application of knowledge, skills and techniques to execute projects effectively and efficiently. It's a strategic competency for organizations, enabling them to tie project results to business goals** "

II. 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.

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

• 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.

III. Project categories

Major construction works are time bound and employ huge resources of men, material and machineries and money. They involve heavy investments and require high level of technology and need an effective management of resources. Construction project refers to high value, time bound, and special construction mission with pre-determined performance objectives. The project categories of

a. **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.
b. **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 firm
c. **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. Construction of manufacturing, processing and industrial plants like steel mills, petro refineries, factories etc.

d. **Special purpose projects** – Environmental works, Emergencies, remedial works and complex key operations

- **Project classifications –**
  - Long , Medium, Short and special short term projects
  - Mega, Large, Medium and small value projects

IV. Role of Project Managers

Project Manager aims to achieve the project mission by

Managing	Time & Progress
	Cost and Cash flow
	Quality and Performance
	Organization behavior
With	Organization resources
By	Planning Resources
	Scheduling Resources
	Organizing resources
	Directing resources
	Monitoring resources
	Controlling resources
Within	Time / cost / quality / environmental constraints

Table 1. Project manager's role

V. 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

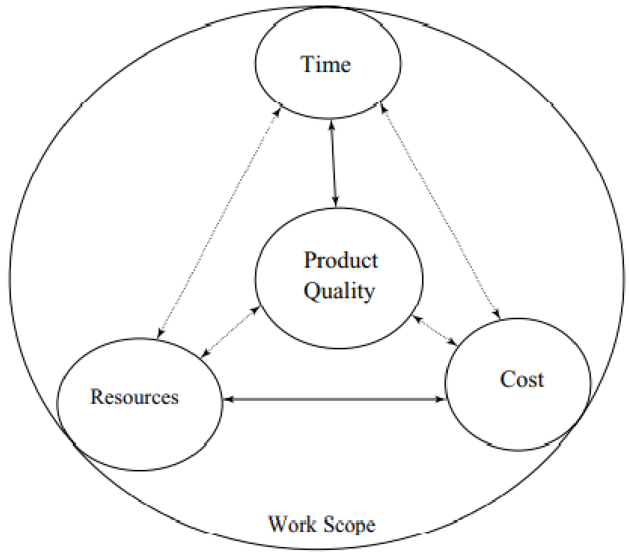


Figure1. Interactive Project Parameters

VI. Construction Project Phases and Processes

1. **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 construction procurement phase, construction (execution and control) phase and close-up (including demobilization) phase. These phases are generally sequential but may overlap in some situations.

2. **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

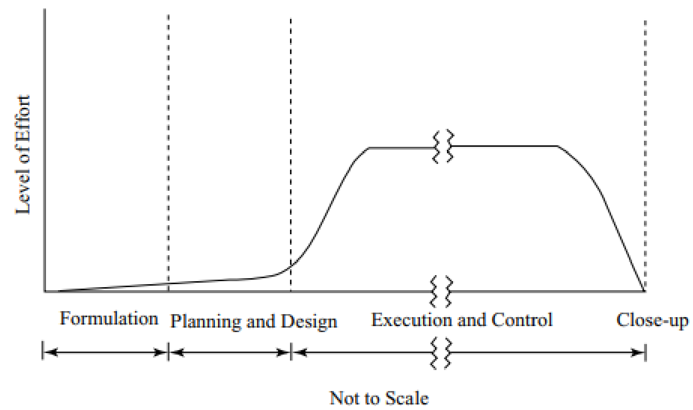


Figure. 2. Project Formulation, Planning and Design, Execution and Control, and Close-up Phases

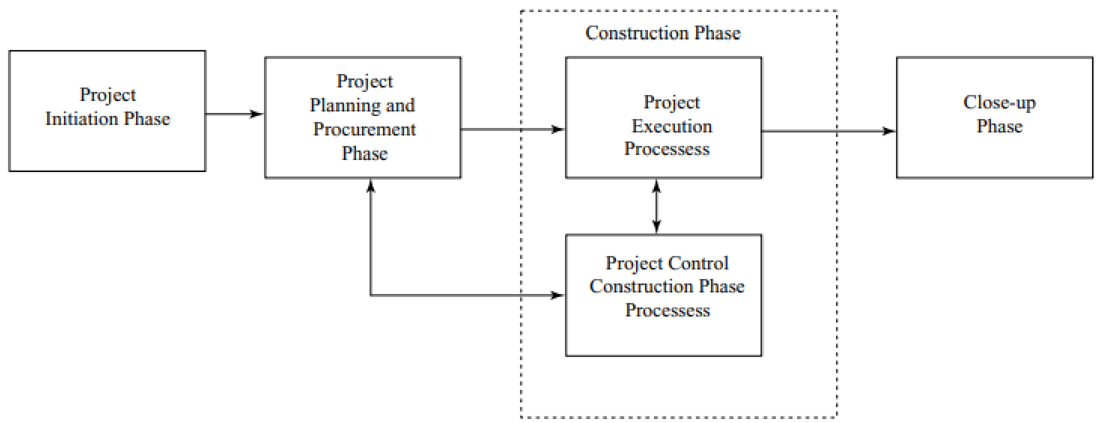


Figure 3. Project Construction Management Phases

A. 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 1.

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:

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 Network-based schedules for complex projects Line-of-balance (LOB) chart for repetitive projects	Project time schedules; activity database
Controlling project schedule	Monitoring methodology	Updated networks and schedules

Table 2. Project Time Management Model

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.
3. **Project Network Modeling and Analysing Techniques.** Project activities modelling 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.
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

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

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

B. 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

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

Table 3. The Project Resources Management Model

1. **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.

2. **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.
3. **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, trenching, cable-laying, and 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.

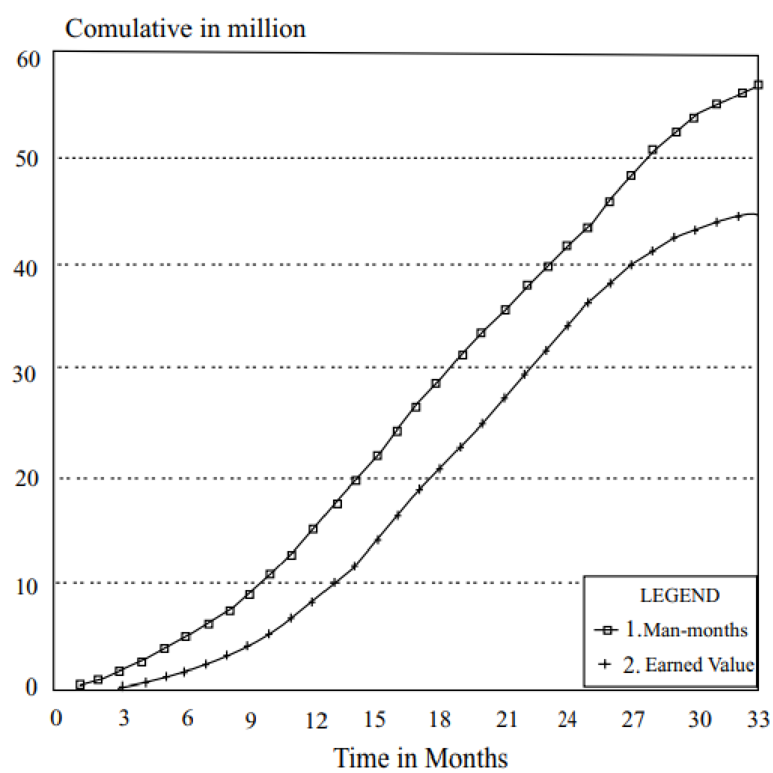
4. **Forecasting resources input and output**. A resource plan shows when and in what quantity the resources are to be inducted at the project site to achieve the project targets. The resource planning focus is to determine what resources (workers, materials, equipment), in what quantities and quality, 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.

5. **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.

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
= Work unit's performed/Material quantity Equipment productivity = Quantity of work done per equipment hour
= Work units/Effort in equipment hours
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 equipment 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



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

Figure 4. Performance curve of the project

Productivity performance variance = Planned productivity – Actual productivity
Productivity performance index = Planned productivity / Actual productivity.

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

VII. PROJECT WORK BREAKDOWN LEVELS

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) 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. At work package level time and cost can be worked out accurately in details 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 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

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.

Table 4. Definition and Classification of Project Work Breakdown Levels

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.

Table 5. Project Work Breakdown Levels of a Medium-Size Project: Salient Features

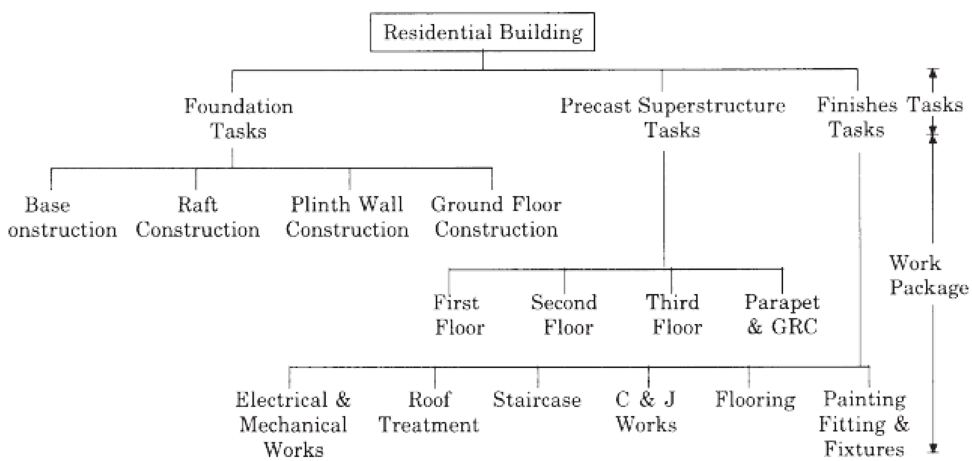


Figure 5. Construction of Residential Building: Tasks and Work Package Levels Structure

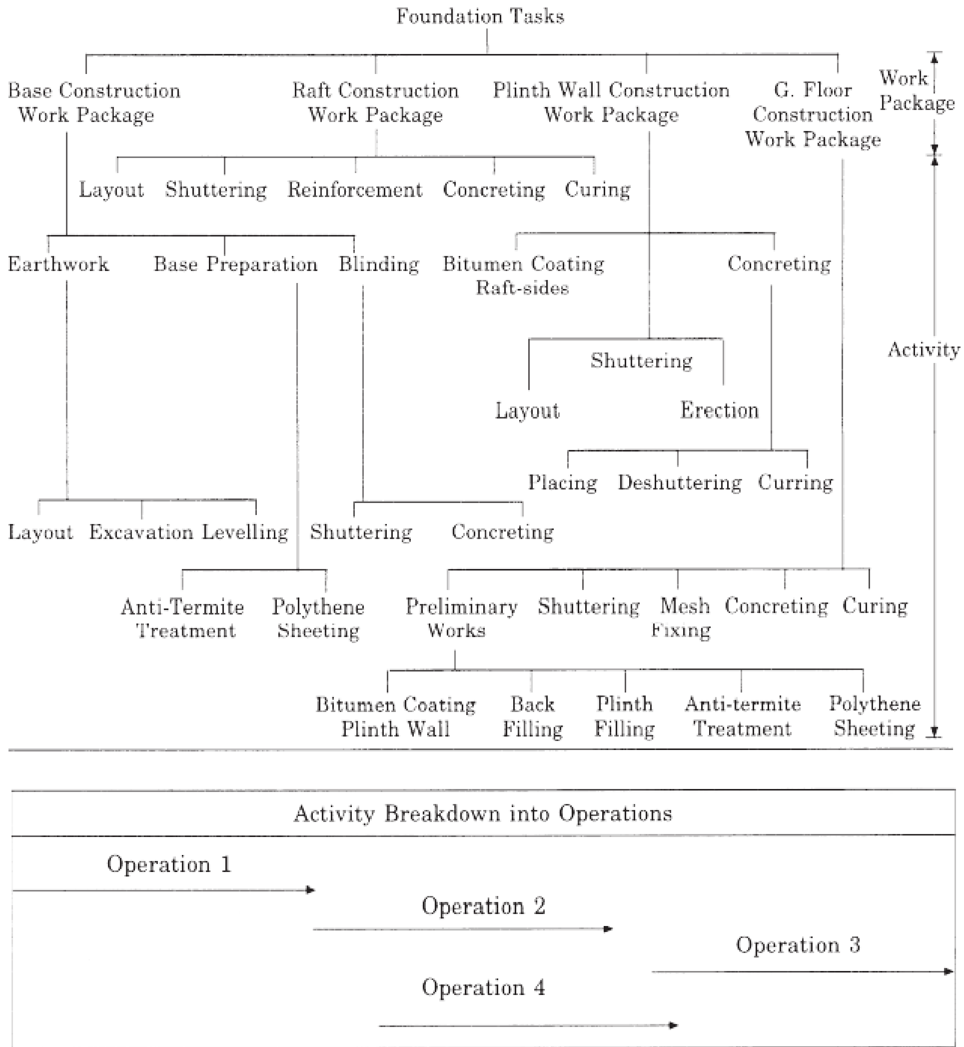


Figure 6. Work Packages and Activity Level Work Breakdown Structure Construction of Foundation Residential Building

Work breakdown of task / work packages into its constituent activities requires a study of the methodology of execution of work packages. Generally known as method statement, derived based on experience or in discussion with project engineers. Construction projects are best managed by work packages, which in turn are best, planned and monitored by activities.

Project planner, uses activity as the common database for planning projects. Activity duration forms the basis for time planning and scheduling of project

The inputs of labor, materials and machinery needed for execution of each activity enable preparation of resources forecasts. Activity base is vital for monitoring progress of the project work.

VIII. PROJECT WORK BREAKDOWN LEVELS

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**.

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:

a. CPM is best suited for developing the sub-networks of sub-groups and task having activities with deterministic single-time duration. The sub-networks can then be systematically integrated into a project network using the PNA techniques.
b. PERT is useful for projects involving uncertainties. In such cases, probabilistic approach of three-times is used for assessing the activity duration.
c. PNA is the commonly used technique for time planning of construction projects.
d. 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.

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.

i. Activity.

A project can be broken down into various activities that are necessary for its completion. An activity 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 construction project.

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

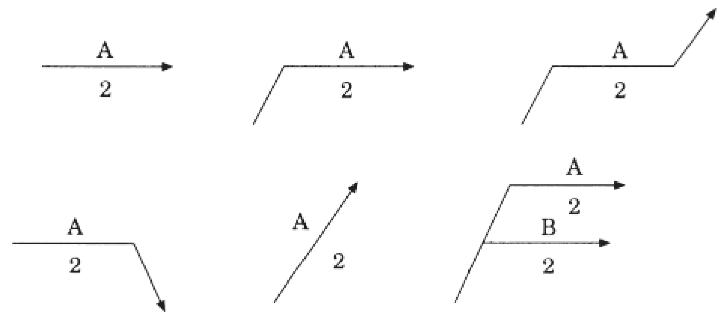
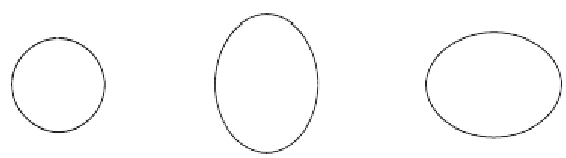


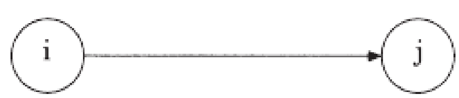
Figure 7. Arrow of an Activity 'A' Drawn in Different Ways

ii. 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



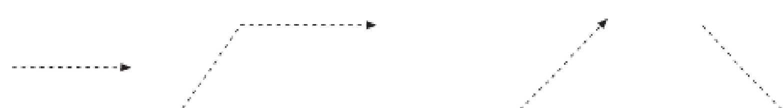
The events are labelled numerically that helps to identify them and describe the connecting activities. The procedure for labelling events is covered in the subsequent paragraphs. An activity (i-j) would be shown as:



iii. 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:



iv. Example-1

Consider a simple task consisting of six activities A, B, C, D, E and F. The durations of these activities are 2, 3, 2, 1, 3 and 2 days, respectively. The network is shown in Figure

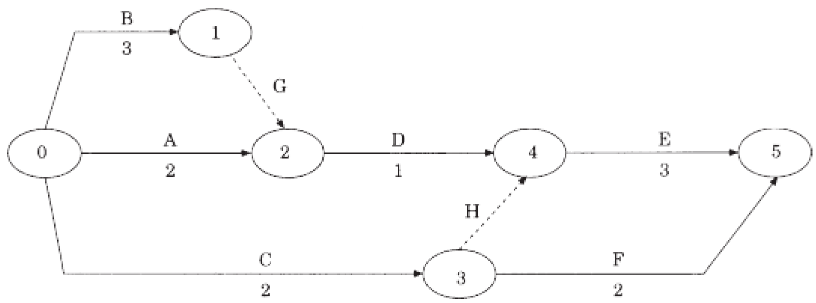


Figure 8. Network of Activities and their Respective Duration

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. 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.

Example 2

Logic sequence 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

Table 6. Logic table of activities

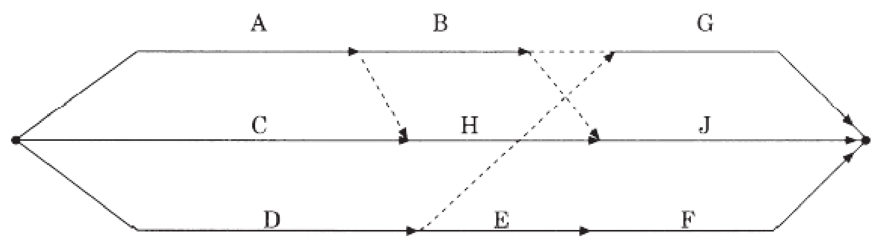


Figure 6. Logic diagram of activities

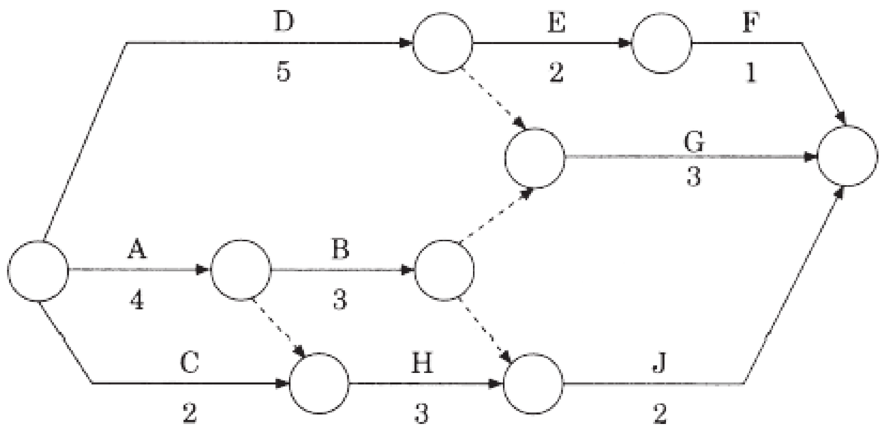


Figure 7. Logic diagram of activities

IX. 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.

i. **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. 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 occurred at their earliest time.

The EET of the first event is set as zero, while the EET of subsequent events is calculated by add ing 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.

$EETj = EETi + d$; largest value if more than one path.

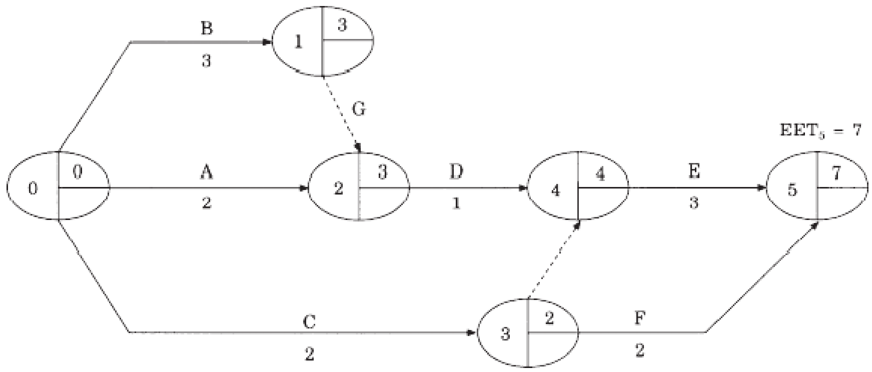


Figure 8. Network Illustrating Calculation of Earliest Event Time (EET)

ii. **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.

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. LETi = LETj – d; 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.

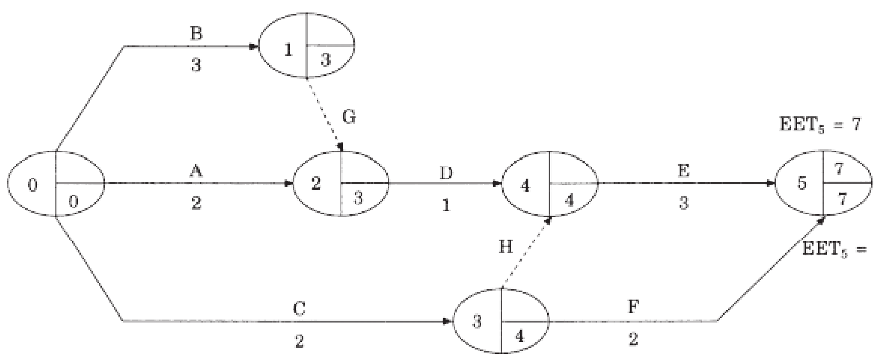


Figure 9. Network Illustrating Calculation of Latest Event Time (LET)

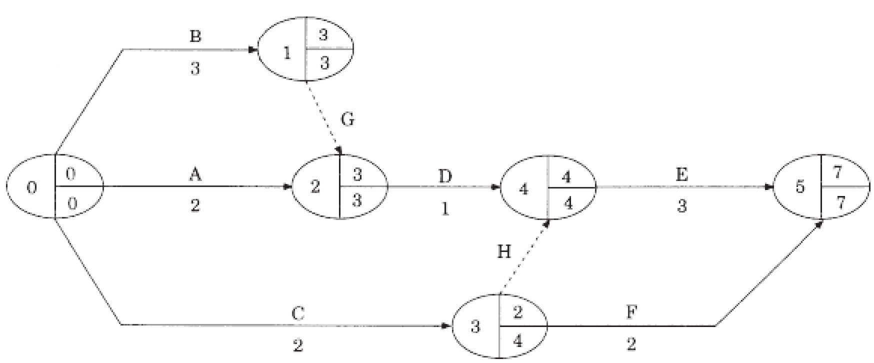


Figure 10. Network Showing Critical Events

iii. **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:

$$LET_3 - EET_3 = 4 - 2 = 2$$

iv. **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 have LETs equal to EETs. These are its critical events.

X. 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.

i. **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,

$$EST = EET_i$$

ii. **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,

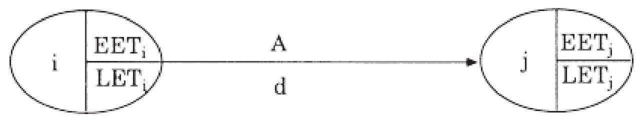
$$LST = LET_j - d$$

iii. **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.

$$EFT = EET + d$$

iv. **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, $LFT = LET_j$

v. **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



vi. **Critical activities.** Activities (including dummy) having a zero float are called critical activities. 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.

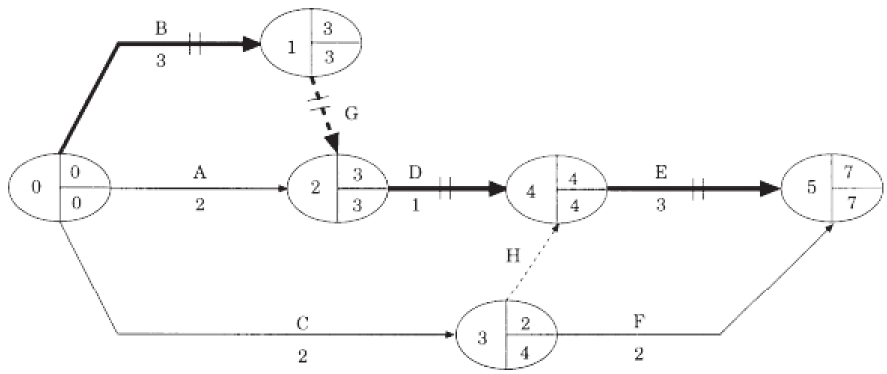


Figure 11. Network Showing Critical Activities with path

XI. 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.

i. **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.

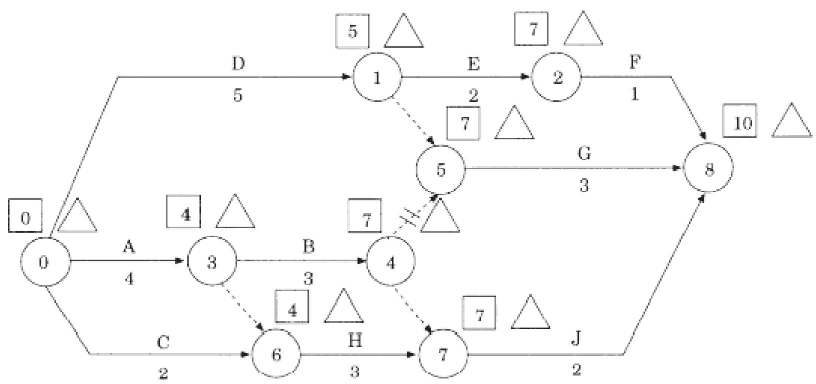


Figure 12. Network Showing Earliest Event Times (EET)

ii. **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.

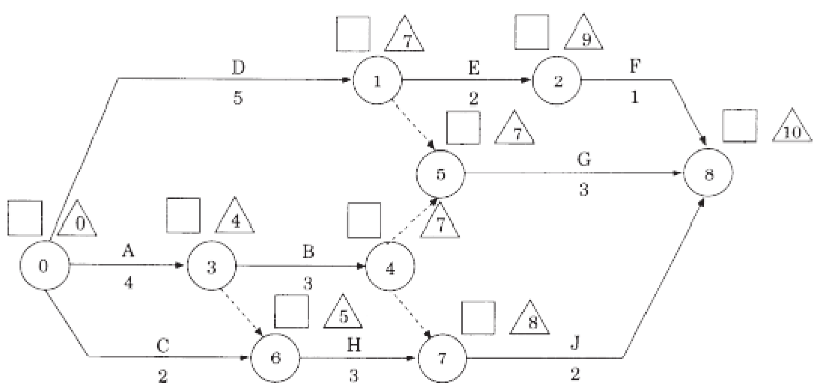


Figure 13. Latest Event Time (LET)

iii. **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, the critical events are 0, 3, 4, 5 and 8.

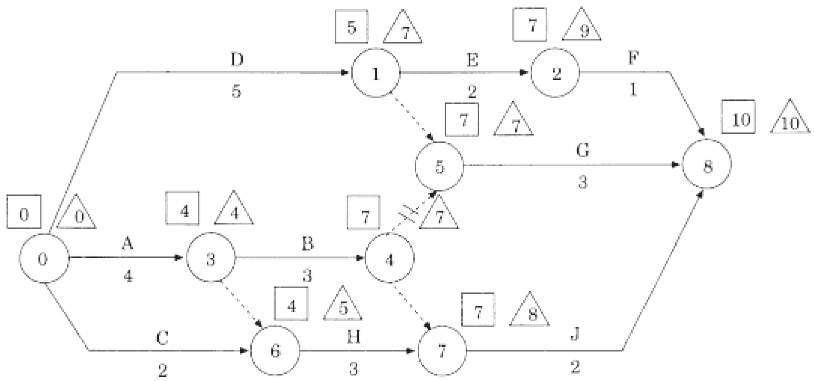


Figure 14. Network showing critical path

iv. **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.

Float = LETj – d – EETi

After identification, the critical activities should be marked on the network using the conventional symbol.

v. **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 deters mines 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 exception’, thereby focusing its attention on the critical activities.

UNIT – II – PROBABILITY ANALYSIS

I. INTRODUCTION - PERT NETWORK MODELLING AND TIME ANALYSIS METHODOLOGY

The Programme Evaluation and Review Technique (PERT) is employed for planning and con trolling the projects involving uncertainties.

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-time estimate for activity duration.

The PERT network making 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 mile stones 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.

II. 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:

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.

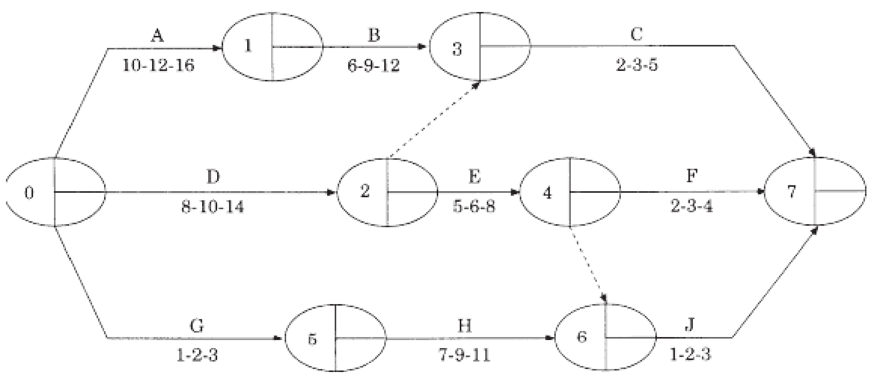


Figure 15. PERT Network

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

Table 15. Expected Activity Timings

Convert PERT network into deterministic model. It is done by changing the three time activity durations in PERT to the one-time expected estimates. Determine critical path. It is obtained by analysing the one-time deterministic model as worked out. Determine critical path. It is obtained by analysing the one-time deterministic model as worked out.

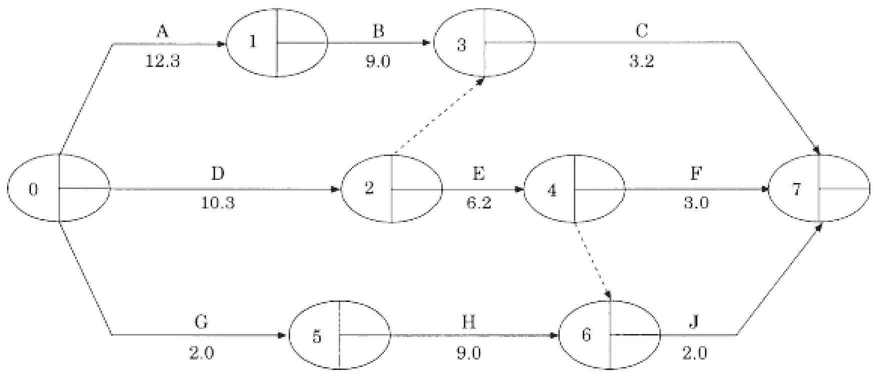


Figure 16. Converting PERT Network into Deterministic Model

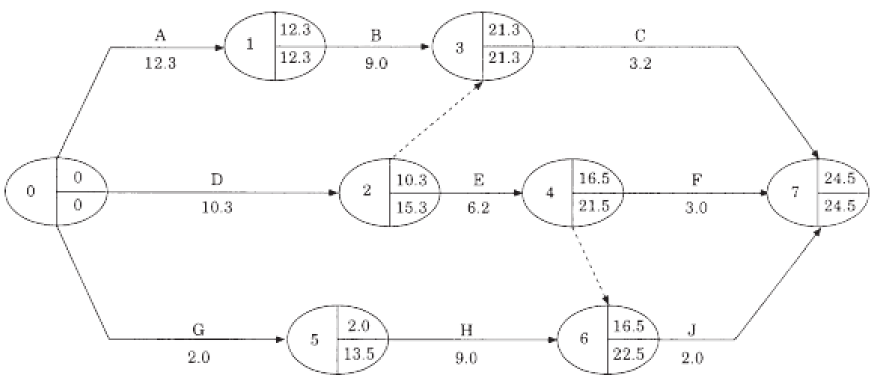


Figure 17. Determining Critical Path

III. 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 prevailing 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. To reduce the number of parameters in the beta distribution and to simplify calculations, it is as sumed that the expected activity duration corresponds to the 50% probability of performance.

Its value is estimated from:

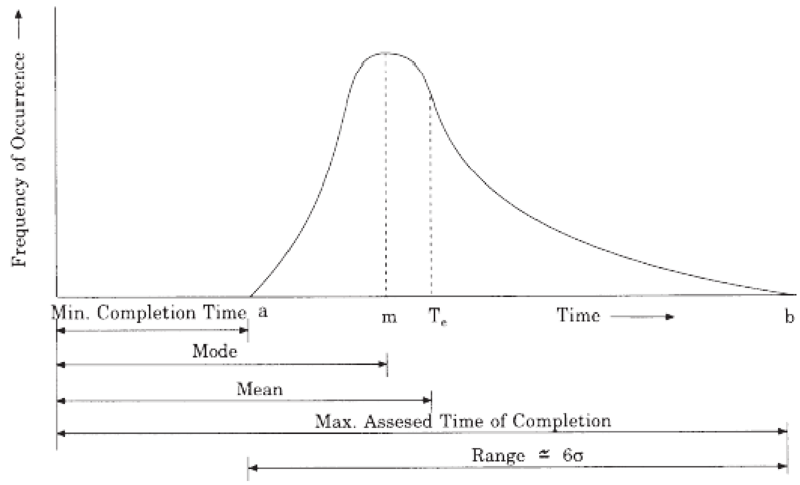


Figure 18. Activity distribution curve

$$\text{Mean value} = \frac{a + 4\text{m} + b}{6} = T_c$$

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

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

$$T_e(\text{A}) = \frac{4 + 4 \times 7 + 16}{6} = 8$$

For Activity B

$$T_e(\text{B}) = \frac{1 + 4 \quad 6 + 23}{6} = 8$$

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, Tp – To) 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 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.

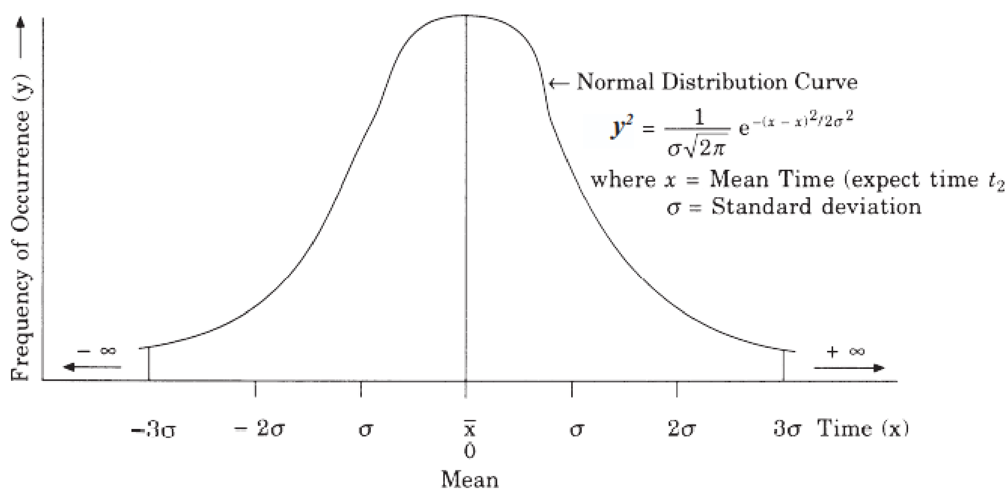


Figure 19. Pattern of Variation of Project Time

- Mean = Sum of the means of critical activities:

$$x = x_1 + x_2 + \ldots\ldots\ldots\ldots\ldots\ldots + x_n$$

= Expected project duration corresponding to 50% probability.

= Mean of Normal Distribution

- Variance = Sum of the variance of critical activities:

$$V = V_1 + V_2 + \ldots\ldots\ldots\ldots\ldots\ldots + V_X$$

= Variance of Normal Distribution

- Standard deviation= √Variance

$$\sigma = V$$

= 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.

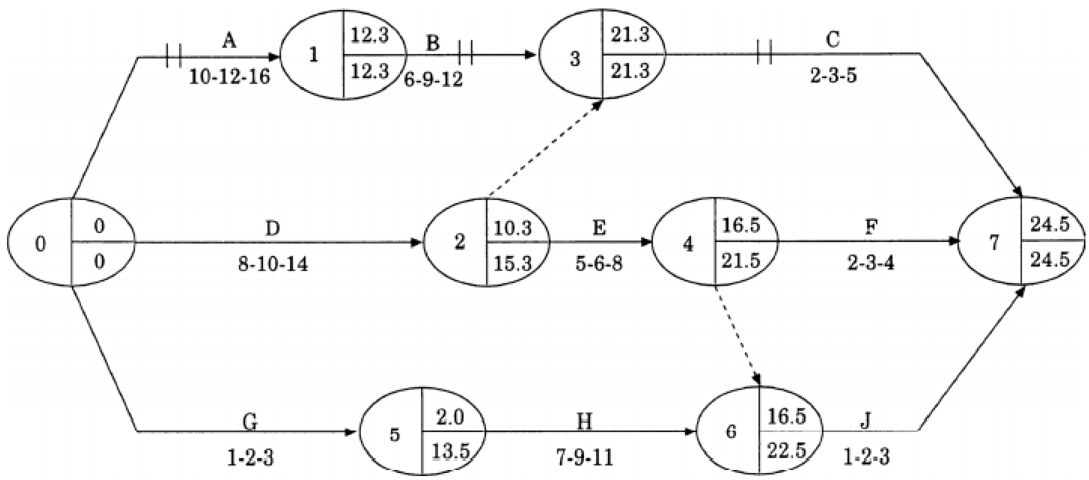


Figure.20 Time Analyzed PERT Network

Further, if there is more than one critical path, the path having the maximum variance is used for determining uncertainty.

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.

$$V = Va + Vb + Vc$$

$$= \left\{\frac{16-10}{6}\right\}^2 + \left\{\frac{12-6}{6}\right\}^2 + \left\{\frac{5-20}{6}\right\}^2$$

$$1.00+1.00+0.25 = 2.25$$

Therefore, project standard deviation is given by:

$$\sigma = \sqrt{V}$$

$$\sigma = \sqrt{2.25} = 1.5$$

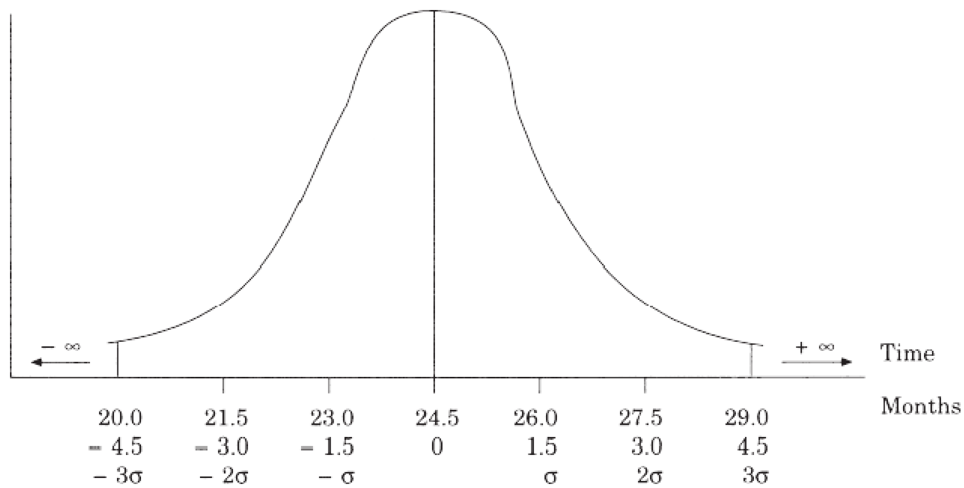


Figure.21 Probability Distribution Graph

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

IV. 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.

	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

Table 16. CPM Vs PERT Original Differences

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.

UNIT – III – PROJECT COST AND RESOURCE ALLOCATION

I. Project time cost Function

i. 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 function provides a ready reckoner for assessing the change in cost with varying project duration and resulting critical activities as shown in figure

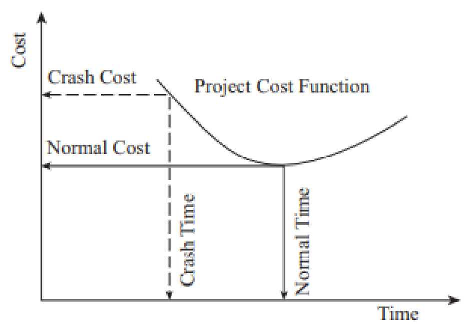


Figure.22 Project time cost relationship

ii. 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

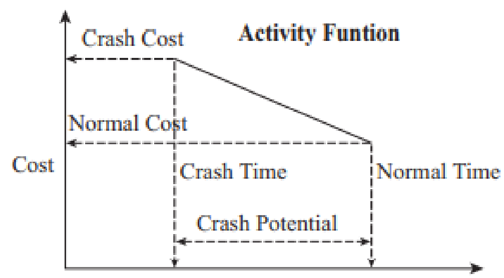


Figure.23 Activity time cost relationship

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.

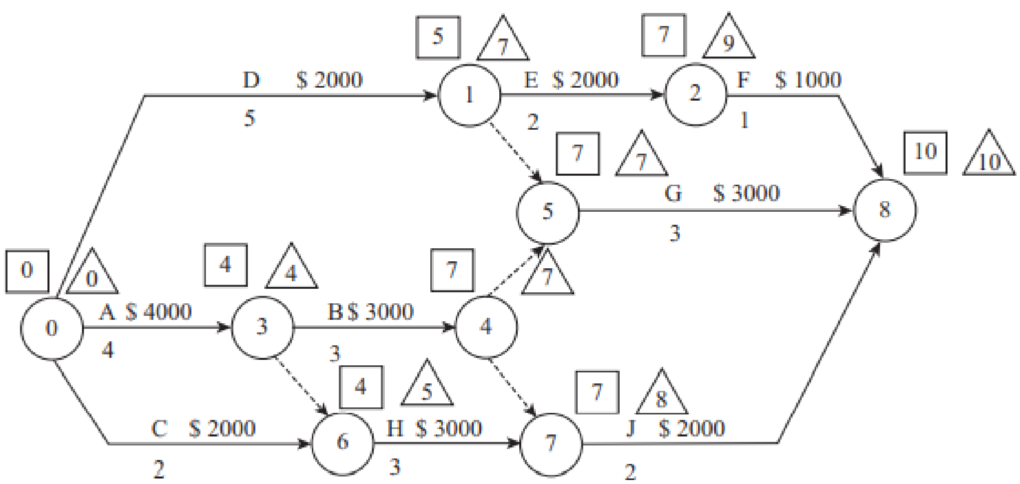
The procedure for project time cost functions

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

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

Table 17. The assessed crashed costs and the crashing potential for a project.



Original Network With Assessed Activity Cost

Figure.24. Analysing the Network: Completion Time is 10 Weeks

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

Table 18. Determine the rate of crashing

iii. **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. 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.

Activity	Lowest Rate of Crashing Crashing Potential	Rate of Crashing ($)/Week
A	2	1500
B	1	1000

iv. **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.

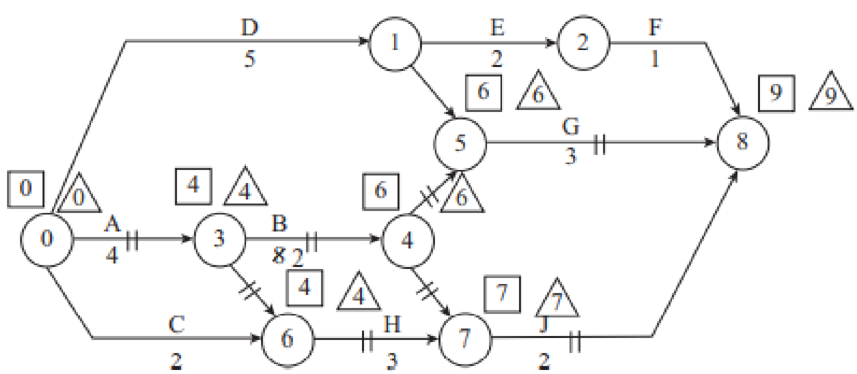


Figure.25. Network after First Crashing: Completion time is 9 weeks

v. **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

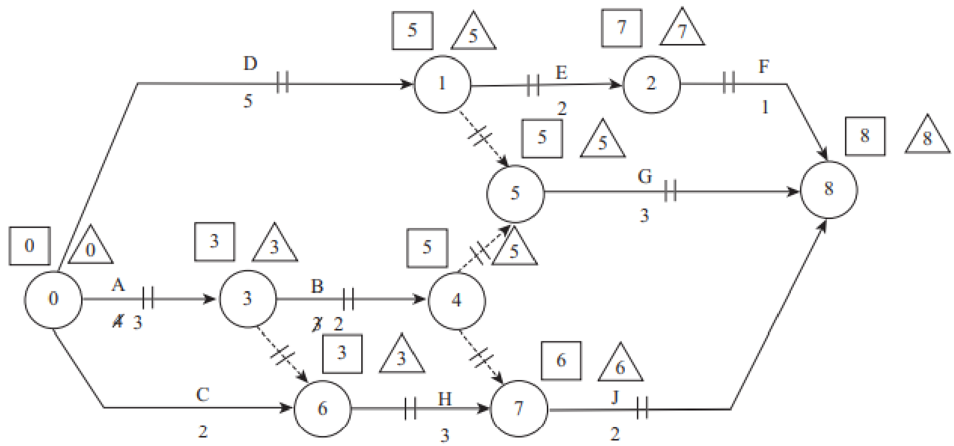


Figure.25. Network after Second Crashing: Completion time is 8 weeks

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

vi. **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

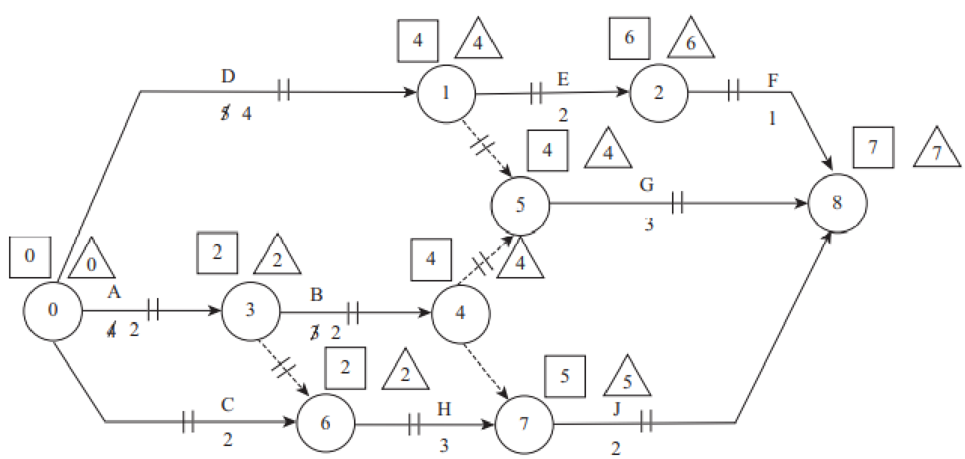


Figure.26. Network after Third Crashing: Completion time is 7 weeks

vii. **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.

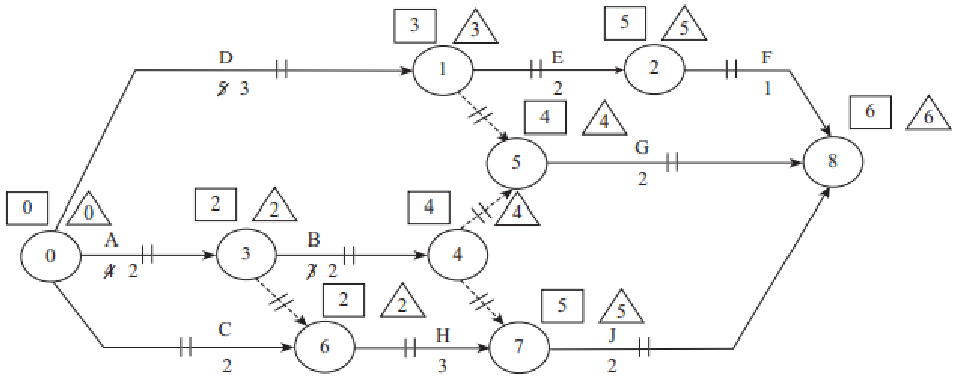


Figure.27. Network after Fourth Crashing: Completion time is 6 weeks

viii. **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.

ix. **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.

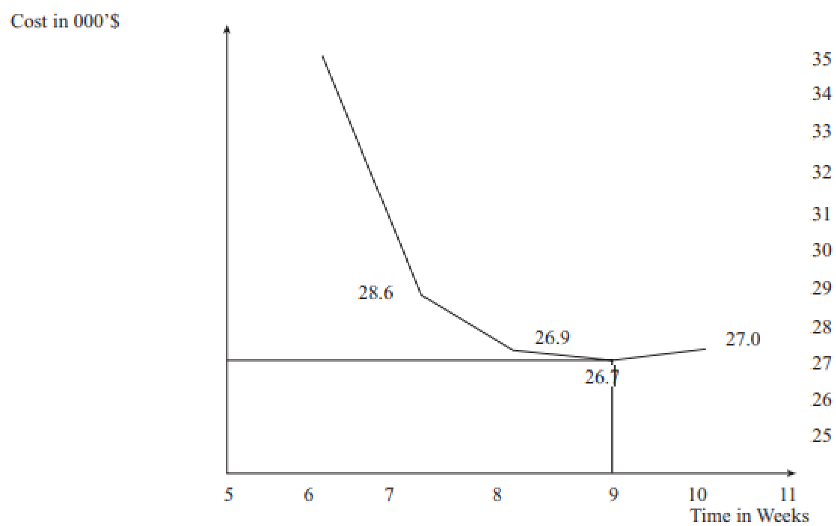


Figure.28. Time cost trade off functions

II. TIME CRASHING

i. 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.

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

Table 19. Determination of the Rate of Crashing

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

III. FACTORS AFFECTING WORK SCHEDULING

The scheduling of a project plan has to take 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. The following guidelines shall be considered during the scheduling.

i. TIME

- Availability of time is crucial limiting factor in a project. More time normally implies less investment. Time and cost are correlated factors. Three aspects of time which have to be considered during the 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 the project duration is not exceeded, such a schedule is called time limited schedule.

b. The schedule must account for holidays, bad weather days and non-working periods. Further affect the working season on production efficiency must also be considered while scheduling activities, 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

ii. MANPOWER

Manpower is the main factor in the successful execution of projects. No amount of automation or machinery can replace the manpower needed for completion of a 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 strikes and breakdown of work are kept in view by management.

The task efficiency of labour, weather conditions, nature of work and the supervisors, leadership – all of these affect the labour productivity. A non-availability of 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 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.

iii. 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 the materials, and their timely supply determines the economics and progress of work.

One method is to stock materials well before they are required so as to ensure timely supply, but the stock inventory costs money. The inventory should be zero before the commencement and after the completion of the project.

To go to 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.

iv. MACHINERY

The availability of machinery is normally, a limiting factor. For example, in an activity involving excavation, the schedule may specify a requirement of tow dozers, but one may actually be available or allotted. This would entail a recasting of the whole schedule. In such circumstances, various alternatives like delay penalty costs, cost of time crashing and the cost of procurement or hiring of additional machinery have to be weighted before making the final decision.

The aim of machinery and equipment scheduling should be to find out the minimum duration schedule in which the employment of equipment and machinery is systematically and uniformly distributed based on its availability or allotment.

v. CAPITAL

Capital is the core of all project activities. The project management aims at economies and the contractor works for earning profits. A proper management of money results in savings while its improper use proves ruinous.

Example

In EST schedule, the large production cost get staggered over a longer period of time, thus reducing investment. But this schedule may not prove attractive to a builder as the saving on investments in earliest stages can be best utilized either on another project or even in earning interest.

The builders schedule, would generally aim to execute those jobs earlier which are more profitable, involve least investment and benefit his cash flow. The client would aim at phasing of construction for early completion.

The network schedule must balance these conflicting requirements.

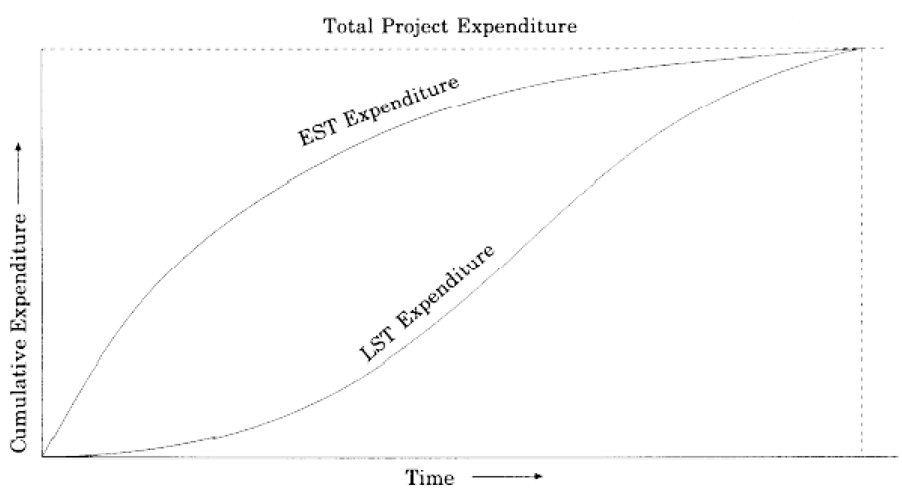


Figure.29. Total Project Expenditure

IV. 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.

i. **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.** e. Plot the forecast of resources graphically. Generally, the cumulative forecasts are in the form of S-shaped curve

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.

ii. **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:

a. **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 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 forecast.
b. **Direct labour forecast.** It shows date-wise, the number and trade categories of workers required. It forms the basis for manpower planning and mobilization.
c. **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.
d. **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
e. **Direct production costs forecast.** This shows the trend and extent the direct product costs of input resources
f. **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 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

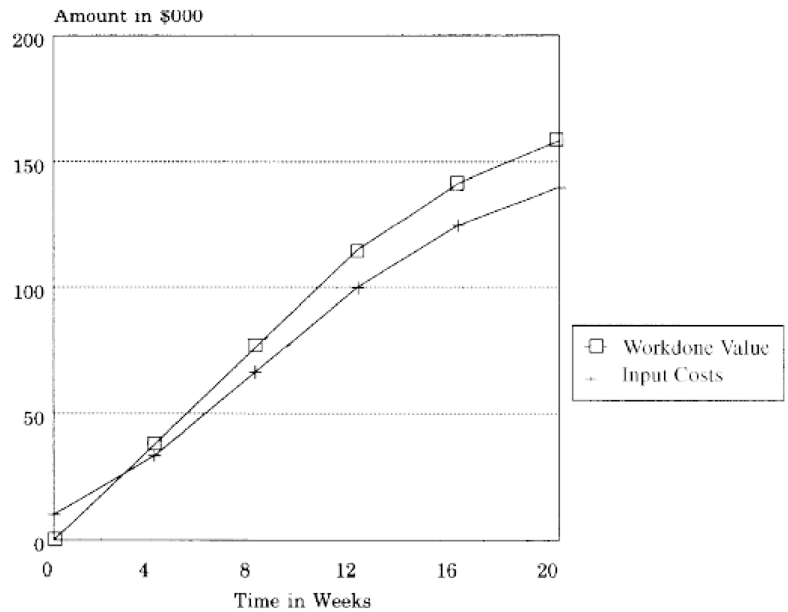


Figure30. Site Development Project: Forecast of Input Costs and Work Done Value (In thousand dollars)

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

Table 20. Daily rate of work forecast

V. 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. The purpose of each schedule is outlined below:

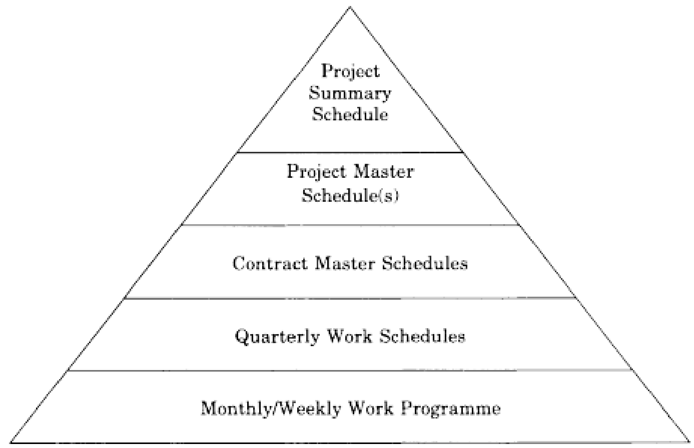


Figure31. Schedule Hierarchy: Project construction phase – Medium Size Project

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 taken as month or 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 works. It is prepared integrating the schedules of sub projects and tasks, or by scheduling the project network.
3. **Contract's master schedule: -** A contract schedule depicts the plan of execution of activities involved in the execution of contracted works. The contract's master schedule is used to
    a. Systematically controls the contracted works, and
    b. 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 master network.

1. **Responsibility center work schedule: -** it reflects the work programme of the responsibility Centre and its scope ranges from a quarter or 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.
2. **Supervisor's work programme: -** This shows the day to day work execution schedule of the supervisors or foreman 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.

VI. PLANNING CONSTRUCTION COST

i. Introduction

Cost accounting and financial accounting systems make use of the same income and expenditure data, but there is a basic difference between them, Cost accounting system is an internal accounting system designed for managing costs in an organization. It provides information for controlling costs whereas financial accounting is a method of presentation of the financial status of the organization to shareholders, legal authorities or financial institutes who are not directly involved in day to day running of an organization.

Cost planning forms a part of the cost accounting system. Construction cost planning encompasses planning judgement, cost techniques and accounting discipline for developing standard costs, financial forecasts, project budget and cost control measures with the ultimate goal of achieving project profit / cost objectives. It uses the standard cost concepts for costing work packages, work items or activities. The work packages standard cost facilitate planning and controlling of costs. Project budget quantifies the project plan in monetary terms and outlines the financial plan for implementation.

The cost of work unit which may be an activity, a work item or a work package is composed of one or more cost elements. The cost elements include labour costs, materials costs, plant and machinery costs, administration costs and other expenses. The process of cost estimation (termed costing) would be simple if it were 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 simplify the planning, forecasting, accounting and controlling costs. It is not always possible to precisely define various cost elements activity wise. In order to identify cost associated with an activity, construction costs generally referred to as production costs are categorized into "direct cost" and "indirect cost" or "overhead".

Production cost = Direct cost + 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 cost.

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	=	Production/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

Figure32. Construction costs breakdown

Production costs are initially estimated for each item of work as stated in the scope of the project work. These are listed under bill of quantities, and can be combined or split up to determine the cost of each work package.

ii. Direct Cost

These are costs of materials, labour and other expenses which can be identified with the execution of an item of work or activity.

Direct cost of permanent work item = Direct material cost + Direct labour cost + other direct expenses

a. Direct Material Cost

These cover all costs connected with materials which become permanent part of the project. These can be measured and costed item wise. For example, materials used in concrete work of specified concrete mix can be both measured, and its cost allocated to concreting activity interms of costs of cement, sand, aggregate, admixture and water, per cubic meter of ready mix concrete.

The direct material cost generally include the following:_

- Purchase cost, ex-factory or specified delivery location
- Transportation costs including freight by rail, road, ocean, custom clearance, insurance and handling charges till arrival at site
- Site manufacturing and fabrication cost to transform raw materials into products for use in permanent works.

It is not necessary to have detailed costing of all types of materials that goes into production of an item. Minor material items like screws, nails and tradesmen's tools can best be grouped under one head “minor materials and tools”

b. Direct Labour Cost

It cover net expenses for procurement, maintenance, and wages of foremen and all category of workers employed at the work site for the execution of an item of project.

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. 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 cost.

c. 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 special purpose plant and machinery cost, such as owning and operating costs of ready mix concrete production, transportation and placing equipment

- Sub contracted activities
- Hired resources costs for execution of specified permeant work, like excavator for trenches.
- Temporary activity required for specific work like erecting a scaffolding platform for plater work.
- Special technical consultant services for architecture, designing, investigation etc, when these are designated as separate activities.

Investigation / trials necessary to establish procedures for undertaking the construction of given work or activity, such as concrete circular wall for a water treatment plant, or driving of foundation piles.

iii. In Direct Cost

Indirect cost includes all cost which are attributable to a given project but cannot be identified with the performance of specific activity or work packages. In other words, all costs other than direct costs are covered under indirect costs. In construction projects, indirect costs or overheads constitute a significant amount when compared to the direct costs. The range of indirect costs, depending upon the nature of the project, may vary from 7.5% to 35% of the total costs.

Indirect Costs of a Typical Small-size Building Construction Project

Sl. 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%

Table 21. Indirect costs of a typical small size building construction project

Indirect costs cover wide range of items. The item of indirect costs depends upon the type and size of the project.

a. **Production overheads:** These include all indirect manpower, indirect materials and other indirect expenses incurred by each production responsibility centre.

Nature of cost	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.

b. **External support services costs:** These cover all indirect manpower, indirect materials and other expenses of the functional set ups concerned with providing technical and logistic support to the production centres

- Technical design and quality control services
- Materials at site manufacturing services
- Equipment supply services
- Personnel and security services
- General services including temporary works and camp utility services.

c. **Administrative overhead:** These contain indirect manpower, indirect materials and other expenses 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 co-ordination management costs
- Technical management costs.
- Marketing, costing and contract management costs
- Resources management costs
- Finance and risk management costs.

d. **Home office overheads:** These overheads represent the expenses related to operations and services rendered by the home office. These costs include 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 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.

iv. Indirect Cost behaviour

An estimator, at the time of costing, computes all the indirect costs in detail or evaluates by using pre-determined company norms. The estimator adds 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, a planner or the cost accountant further splits up each items of indirect cost into three broad categories ,i.e. variable cost, fixed cost and semi variable costs.

a. Variable cost:

Variable cost tends 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 changes in the volume of production

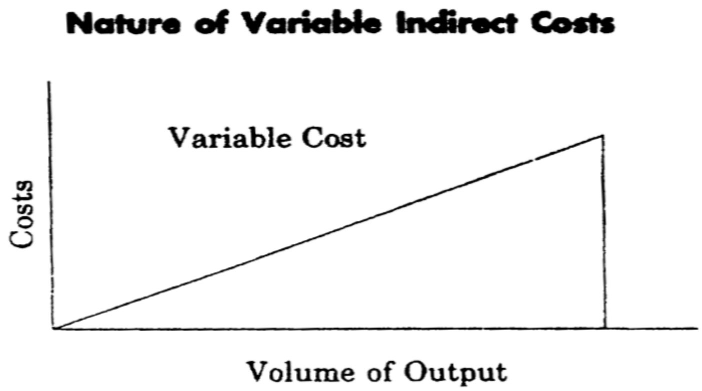


Figure33. Variable cost

b. **Fixed cost**

Fixed costs do not show any appreciable fluctuations with changes in production levels.

These costs are either onetime costs like the camp construction cost or periodic cost such as supervisor's salary for a period of six months or monthly recurring expenses like monthly rent for project office and monthly depreciation for project construction equipment.

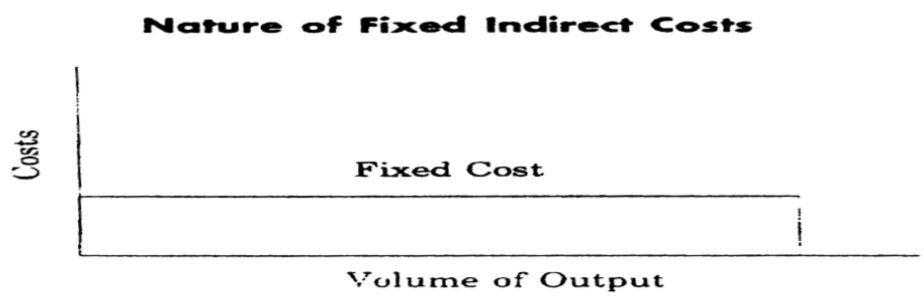


Figure34. Fixed cost

c. **Semi Variable cost:**

Semi variable costs are partly fixed and partly variable in nature. Example of these are telephone expenses which consists of fixed installation expenses, and variable operating expenses which vary with the volume of work or production activities.

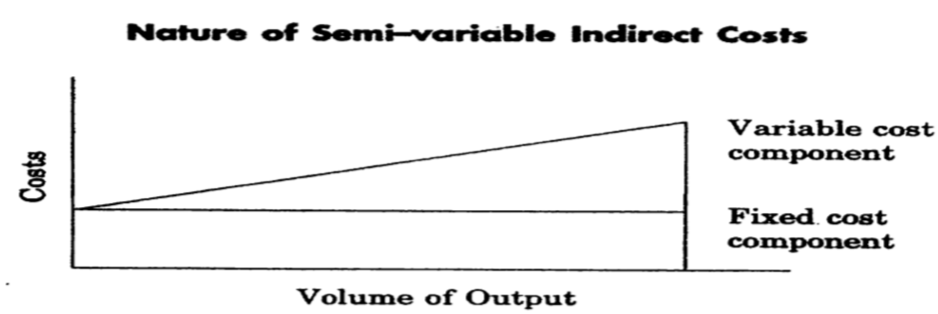


Figure35. Semi variable cost

It is not always feasible to clearly demarcate indirect costs into variable and fixed categories as many cost behaviour patterns are possible. There are indirect costs which may display rising mixed behaviour patterns. i.e material prices get discounted with an increase in the order quantity. It is not always feasible to clearly demarcate indirect costs into variable and fixed categories as many cost behaviour patterns are possible. There are indirect costs which may display rising mixed behaviour patterns. i.e material prices get discounted with an increase in the order quantity.

But for apportioning indirect costs, it is necessary to divide each item of indirect cost broadly into

a. production related variable indirect costs and
b. periodic or time related fixed indirect costs.

UNIT – V – SOFTWARE APPLICATIONS

I. INTRODUCTION

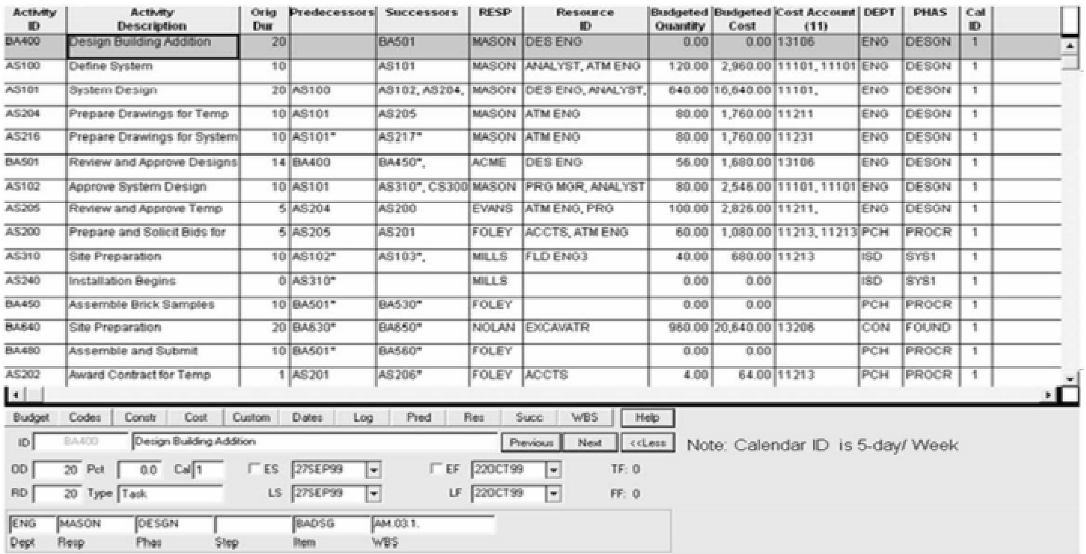
i. Introduction

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 Sure Trak, 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.

ii. Project management software salient features

The latest project management packages have most of the following features:

- Planning and Schedule Development facilities; Scheduling Project Work and Resources 297
- 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.



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

Figure36. Primavera APEX Project Input Data Sheet

iii. Planning, Schedule Development and Organising Facilities

- These include preparation of networks, activity schedule matrix, project bar chart schedule, time scaled network, scheduling and resource levelling-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, 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.

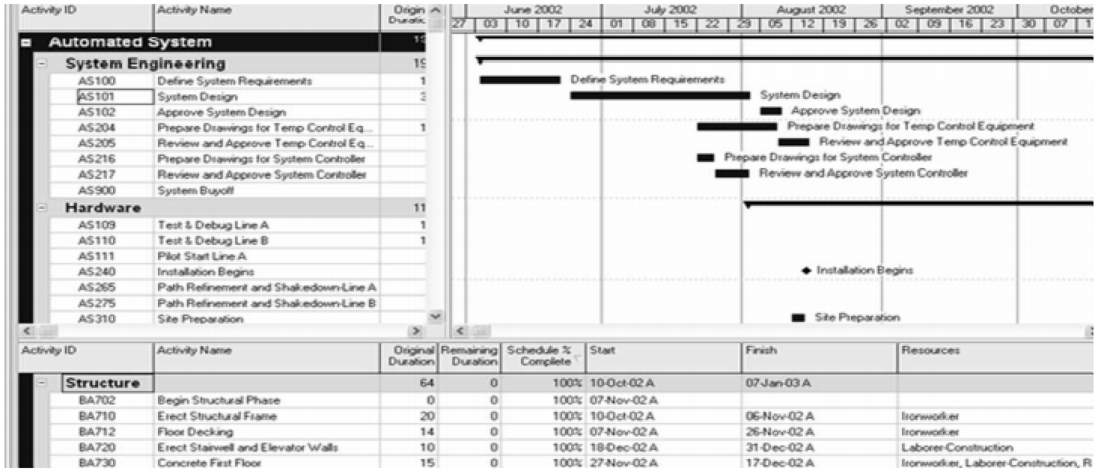


Figure 37. APEX Project: Classic Schedule Layout with Bar Chart Scheduled by Dates

iv. 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:

- 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

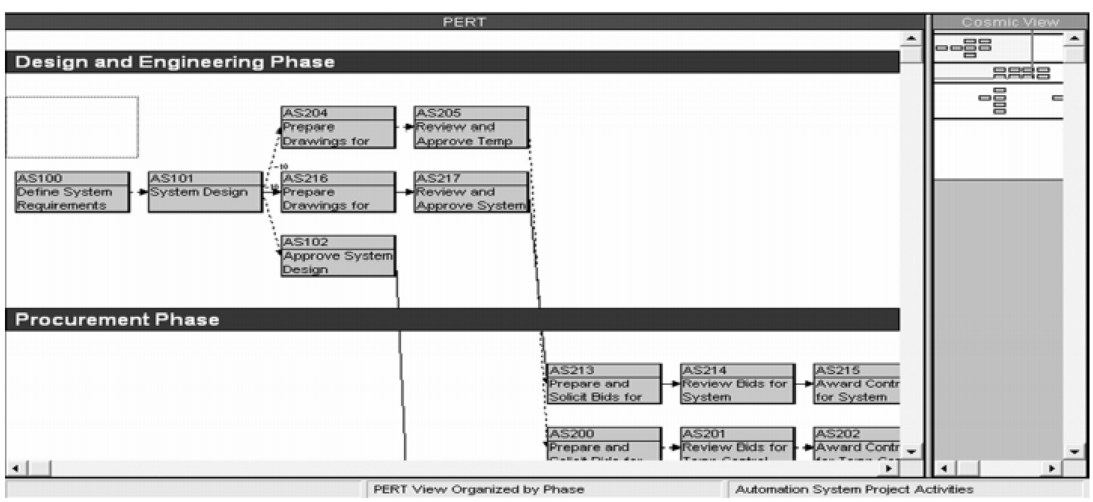


Figure 38. APEX Project: PERT with Cosmic View by Phases

v. 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 levelling 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.

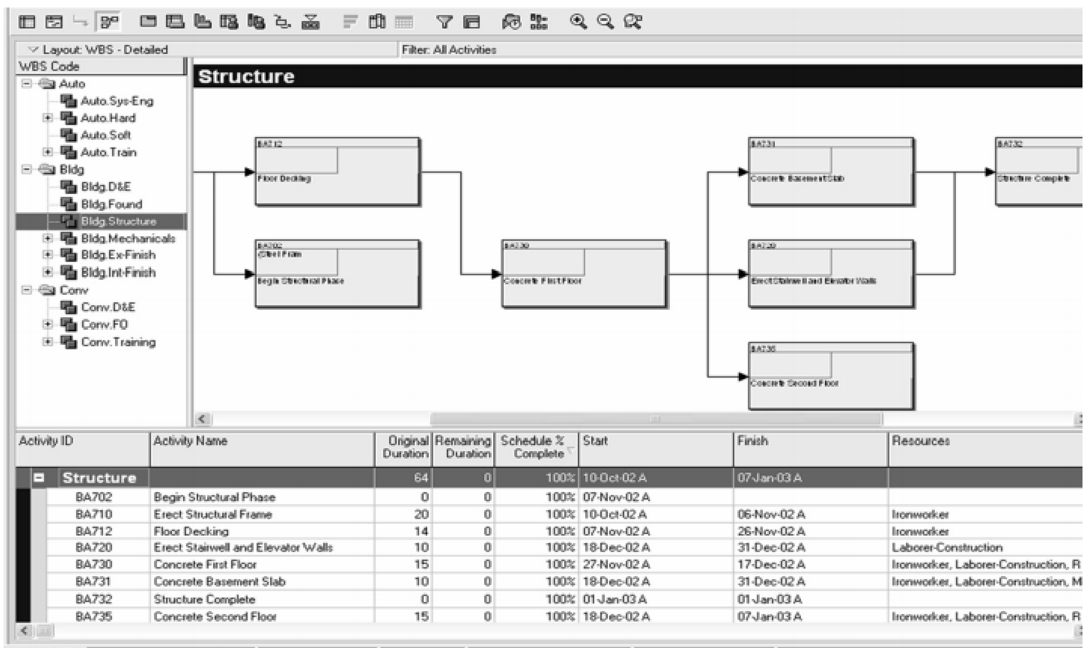


Figure 39. APEX Project: Activities Details with Sub-Network

vi. 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.

vii. 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.

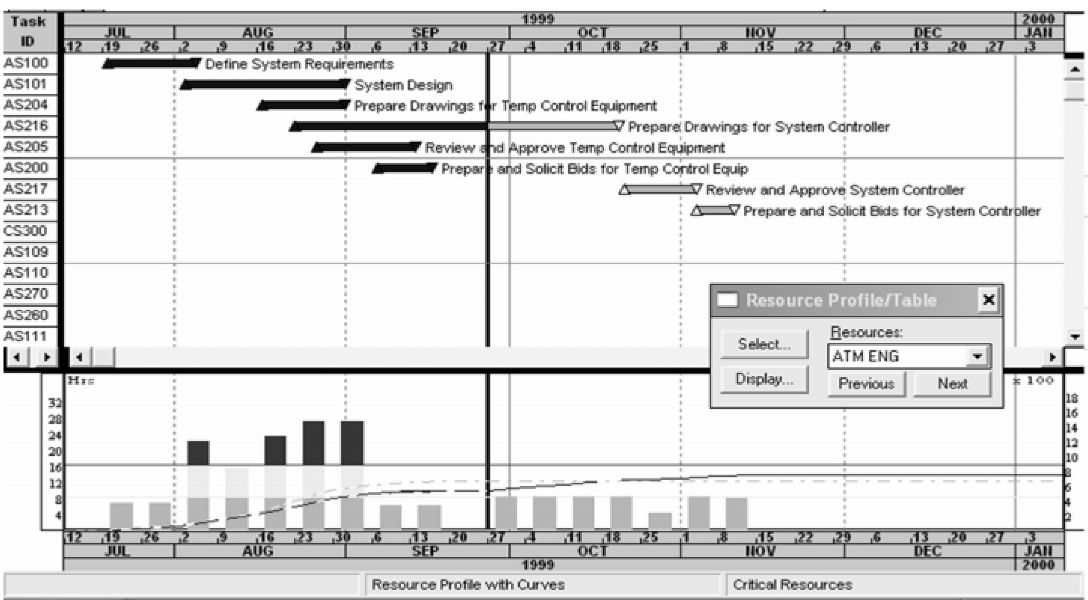


Figure 40. APEX Project: Resource profile with curves

viii. 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
- 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

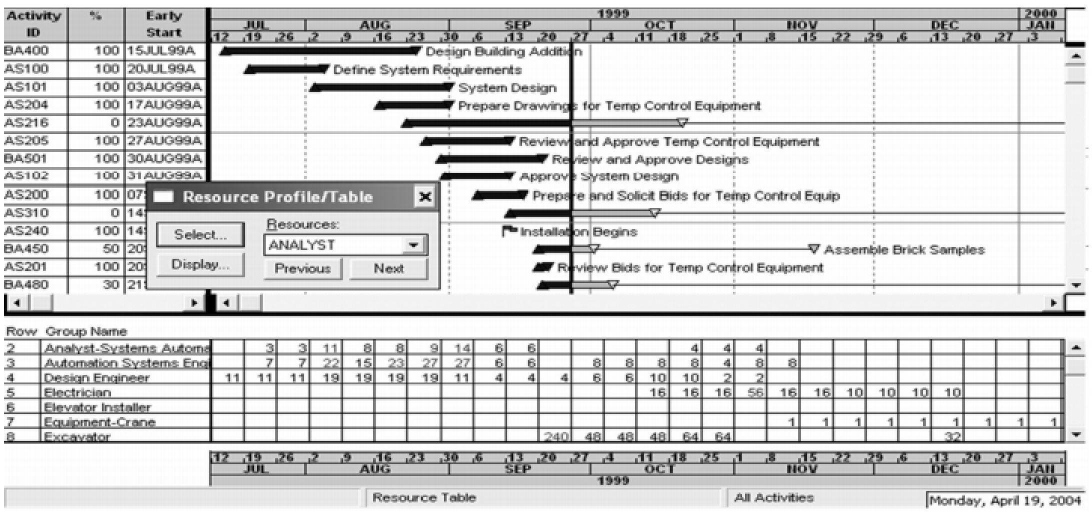


Figure 41. APEX Project: APEX Project: Resource Table

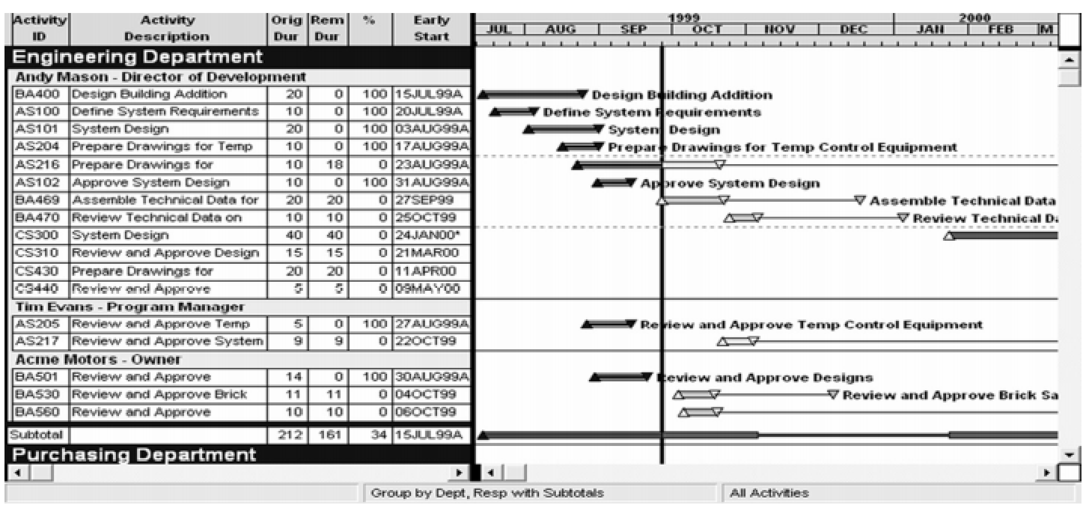


Figure 42. Apex Project: Updated Schedule Layout; Group by Dept.; Resp.