Hawassa University

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Department of Construction Technology and Management

Construction planning and Scheduling (CoTM 3402)

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Project planning scope

Contents of the lecture

- ✓Plan development Process
- ✓Time planning process
- ✓Work scheduling process
- ✓Resource planning process
- ✓Project control process
- ✓ Importance of planning, scheduling and controlling projects

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1. Plan development process

Planning process

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

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➔Scheduling means putting the plan on a calendar time scale. During execution stage, monitoring brings out the progress made against the scheduled base line. Control deals with formulation of and implementation of corrective actions necessary for achieving project objectives. In the construction phase of project development, planning and controlling are in separable. During project implementation, the plan-do-monitor-communicate re-plan(when necessary) is a continuous processes. In this context , the term planning broadly includes the plan-making, scheduling and controlling processes.

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- Process involved in construction planning can broadly be divide in two;

Planning time
✓What is to be done?
✓What are the activities involved?
✓How it is to be done?
✓Where it is to be done?

Planning resource
✓What is needed to do it?
✓Who is to do it?

Planning Implementation
✓How to organize control system?
✓How to monitor what is done?
✓How to analysis variance?
✓How to forecast trends?
✓How to communicate performance?

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- The construction planning process is stimulated through the study of documents.
- These documents include-but not limited to;
  - The available technical and commercial studies and investigations
  - Designs and drawings
  - Estimate of quantities
  - Construction method statements
  - Project planning data
  - Contract documents
  - Site conditions
  - Working regulations
  - Market survey
  - Local resource
  - Project environment and,
  - The client's organization

The planning process takes into account the strengths and weakness of the organization as well as the anticipated opportunities and risks.

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- Planning follows a systematic approach. Various planning techniques are employed to systematize and transform the mental thought process into a concrete project plan.

Project Planning Process

Planning data collection	Where to look for data?	Studying the relevant documents
Planning time	What is to be done? What are the activities involved? How it can be done? When it is to be done? Where it is to be done?	Define scope of the work Breakdown project into activities Developing network plans Scheduling work Charting site layout
Planning resource	What is needed to do it? Who is to do it?	Forecasting resource requirement Planning the 4M'S Designing organizational structure Allocate tasks and resource Establishing responsibility centers
Planning implementation	How to account performance? How to monitor performance? How to communicate information?	Designing control systems Formulating monitoring methodology Developing project management information system(PMIS)

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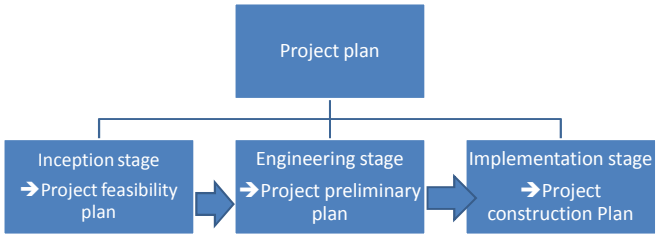
Project Planning Techniques

Stages	Planning process	Techniques/methods
Planning time	Breaking down project work Developing time network plan Scheduling	Work breakdown Network Analysis, BC&LOB Time limited scheduling Resource limited scheduling
Planning resources	Forecasting resource requirement Planning manpower requirement Planning materials requirement Planning equipment procurement Budgeting costs Designing organizational structure Allocating tasks and resources	Forecasting Manpower scheduling Materials scheduling Equipment selection and scheduling Cost planning and budgeting Organization design Resource allocation
Planning implementation	Formulating monitoring methodology	Resource productivity control Time control Contribution control Budgetary control

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Types of project plans

Planning the entire project from its inception to completion requires a vast coverage, varied skills, and different types of plans. The nature of plan encountered in a typical construction projects are;



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- **Project feasibility plan**

➔Planning by the client begins as soon as he gets the idea about developing the facility to fulfill certain motives. His early thought process conceptualize the cost, time and benefit implications of the project. Only when he is convinced about the soundness of his idea does, he decide to go ahead with the feasibility studies.

➔The feasibility study team examines the needs of the client and ways to fulfill them. It defines the over all scope of work, and assess the time and costs of accomplishing the project. This outline plan, developed by the feasibility team during inception stage, forms the basis for identifying projects objectives and developing the project plan.

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- **Project preliminary plan**

➔Acceptance of the feasibility studies marks the commencement of the preliminary plan-making process. It main aim is to provide direction to the client mangers and staff employed during the development phase of the project. The project preliminary plan forms the basis for developing the project construction plan. The preliminary plan includes;

✓ A project time schedule and skeleton network to highlight the work dependencies, project milestones and the expected project completion time

✓ The project design and drawings preparation schedule

✓ A breakdown of project work into contracts, along with a schedule of contracting activities, including the tender preparation period, tender finalization period, and the contracted works commencement and completion dates.

✓ A resource preliminary forecast indicating the phased requirements of men, important materials, plant and machinery.

✓ Resource procurement system

✓ Project organization and staffing pattern

✓ Preliminary forecast of funds requirement

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- <u>Project construction plan</u>

the project construction plan includes;

➔Time plan➔ it depicts the schedule of project activities for completion of the project within the specified time.

➔Resource plan➔ it forecasts the required input resources of men, Machinery and money for achieving the project completion time target and cost objective.

➔Plan for controlling project ➔ it encompasses the design of control system, monitoring system, codification system and the computerized information system.

- The construction projects plan development process is divided into three parts; time planning, resource planning and project control system planning. These parts are interdependent and not mutually exclusive.

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2. Time planning process

- A plan prepared well before the commencement of construction in a project, can be instrumental in formulating directions, coordinating functions, setting targets, forecasting resources, budgeting costs, controlling performance and motivating people. However, the absence of a project time plan almost makes certain that a project can not be completed on schedule without incurring extra costs.(Benefit of planning)
- The time planning process involves the following three stages;

(a) Project work breakdown➔ this means breaking sown the scope of project work into its constitute sub-projects, tasks, work packages and activities.

(b) Modeling and analyzing networks➔ this include developing logic diagrams or sub-networks; integrating these to develop a time-planning model(Usually a network), and; analyzing this model to determine the project completion time.

(c) Scheduling work programme➔ this involves putting the time plan on a calendar basis, and using the scheduled programme to forecast inputs and out puts.

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3. Work scheduling process

- Scheduling means putting the plan on calendar basis. A project network shows the sequence and interferences of activities, their time durations and earliest and latest completion time, but this needs to be scheduled to determine commence and termination dates of each activity, using optimum resources or working within resource constraints. A time schedule outlines the project work programme, it is a time table of work.

- Scheduling procedure

➔The scheduling methodology varies with the planning techniques and the nature of the task to be performed. A tool containing the commonly used techniques for planning, scheduling and monitoring is indicated in the next slide.

➔Each Scheduling Techniques has its own merits and demerits. But ultimately scheduling are best presented in the bar chart form for ease of comprehension and communication. These bar charts are supplemented with appropriate planning technique for monitoring the progress of the projects.

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Commonly used time planning techniques in construction project management

Sl.NO	Nature of the project	Planning	Scheduling	Monitoring	Displaying
1	Simple project/sub project (a)Non-repetitive work (b)Repetitive work	 Bar Chart LOB	 Bar Chart LOB	 Bar Chart LOB	 Bar Chart LOB/Bar chart
2	Complex sub-projects (a)Deterministic (b)Probabilistic	CPM PERT	Time scale Network >>	CPM	Bar Chart >>
3	Complex Projects (a)Non-repetitive W. (b)Repetitive work (c)Probabilistic	PNA PNA PERT	Bar Chart LOB Time Scale network	PNA LOB PERT	Bar Chart Bar Chart/LOB Bar Chart
CPM-Critical Path PERT-Programme Evaluation and Review Techniques PNA- Precedence Network Analysis LOB-Line of Balance			BC-Bar Chart TSN-Time Scale Network/Logic Bar Chart		

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- The scheduling procedures, depending upon type of project can be broadly divided into two categories;

1. Scheduling non-repetitive network based projects
2. Scheduling repetitive projects using line of balance techniques

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1. Procedure for Scheduling non-repetitive network based projects
- ✓ Outline scheduling constraints
- ✓ Design scheduling calendar
- ✓ List activities in order of sensitivity
- ✓ Draw earliest start time schedule
- ✓ Determine resource optimization criteria
- ✓ Schedule critical activities
- ✓ Schedule non-critical activities
- ✓ validate time objectives
- ✓ Schedule other resource
- ✓ Schedule within resource constraints
- ✓ Schedule repetitive work projects

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2. Procedure for Scheduling repetitive projects using line of balance techniques
- ✓Outline schedule constraints
- ✓Tabulate scheduling data of a unit work cycle
- ✓Prepare a logic diagram of a unit work cycle
- ✓ chart scheduling calendar
- ✓Prepare earliest start time schedule
- ✓ Analyze earliest start time schedule
- ✓Prepare optimum schedule leaving adequate buffer
- ✓Draw Line-of-Balance work schedule

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4. Resource planning Process

- Forecasting inputs and outputs

➔The inputs and output forecast includes the data-wise requirement of project manpower, major materials, costly equipment, production costs, earned value of work done and the expected income. The basis of forecasting is the schedule of work.

➔ Inputs and outputs forecast aids in conceptualization of project. It indicates the quantum of resources required for executing is project the output expected. The pattern of input resource form the base for evaluating such needs as workers' accommodation, materials storage, equipment work-load and project funding pattern.

- Planning construction work force

➔the project manpower planning primarily focuses on determining the size of the project work force, its structuring into functional groups and workers' teams, and scheduling the manpower recruitment/induction to match the task requirements.

➔ This process chiefly involves identifying the trades or the skills required, establishing productivity standards to determine the number of workers needed to perform a given job in the specified time, data-wise forecasting of the workers' requirements for accomplishing the project work, and , finally, organizing the planned workforce into operating work-teams having assigned programmed tasks.

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Resource planning Process

- Planning construction materials

➔the construction materials planning involves identifying the materials required, estimating quantities, defining specifications, forecasting requirements, locating sources for procurement, getting material samples approved, designing materials inventory, and developing the procurement plan to ensure a smooth flow of materials till the connected construction works are completed at the project site.

- Planning construction equipments

➔Equipment planning for a project aims at identifying the construction tasks to be undertaken by mechanical equipment, assessing the equipment required, exploring the equipment procurement options and, finally, participating in the decision-making for selecting the equipment

- Planning construction standard costs & planning construction Budgets.

➔the construction cost plan uses standard cost concept for costing work-packages, work items or activities. The standard cost technique finds wide applications in estimating, forecasting, budgeting, accounting and controlling costs.

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5. Project Control Process

- Control involves organizing the control responsibility centers, designing accounting and monitoring methodology, codifying data and developing the information system so as to make-decisions speedily. It also includes identifying the problem areas, making risk-taking decision to tackle the problem, organizing and directing resources needed to carry out these decisions, and measuring the results of these decisions against targeted expectations through organized and systematic feedback.
- An efficient control system improves productivity of men and materials, economizes employment of resources, enables understanding of time and cost behaviors, provides yard-stick for measuring performance, generates information for updating resource planning and costing norms, prevents pilferage and frauds and assists in formulating bonus or incentives scheme for motivating people.

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Project Control Process

- Project control Methodology

➔the project control follows the system concept. Each organizational unit in a project, usually referred to as the responsibility center, can be viewed as a sub-systems are highly interdependent and interactive. The performance objective of a sub-system are stated in terms of the parameters to the controlled. These parameters include the time progress targets, resource productivity standards and the work-package standard costs and sales target. Each sub-system accounts for its performance and reports its actual performance to the monitor. And it is these reports that serve as early warning signals of ensuing dangers.

- Control resource productivity

➔productivity control aims at ensuring efficient utilization of inputs of men, materials and equipments by identifying cases of their wastage as well as affecting improvement to minimize it. The case of wastage are located by analyzing variances and efficiency of planned and on-site actual productivity;

Productivity performance variance=planned productivity-actual productivity

Productivity performance index=planned productivity/actual productivity

The methodology used for controlling the parameters (Labor productivity, equipment productivity and material productivity) can be divided into four stages;

➔Defining the control purpose, measuring the actual performance, computing the productivity performance variance and identifying their causes for effecting improvements.

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Project Control Process

- Control Costs

➔It involves the processing of reports received from various responsibility centers or operating divisions, relating the costs incurred with the set standards, analyzing the reason for any variances and presenting the results to the project management for decision-making and initiating remedial measures.

- Controlling time

➔the project time control aims at timely execution of work as per the work programme and applications of corrective measures in case of deviations.

➔ The time control process involves the monitoring of time status by updating the project network and time schedules, reviewing durations of balance activities, computing deviations and evaluating the implication of deviations on project time objective by time-analyzing the project network. It includes formulating remedial measures including what-if analysis, time crashing, re-planning, re-forecasting and re-mobilizing resources under changed situations with a view to accomplish the time objective.

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6.Importance of planning , Scheduling and controlling projects

- **Planning benefit**

✓ Project plan clearly defines project scope of work. It breaks down project objectives into clear, identifiable, quantifiable, attainable and verifiable goals which are assigned to individuals and responsibility centers for accomplishment.

✓ Project plan aids the management in performing its functions efficiently and effectively.

✓ Project plan forms the basis of a project operations and directions and shows how the project is to be run. It also specifies the committed future course of actions on the basis of current decision made with available knowledge of future.

✓ Project plan identifies critical activities, thus enabling the managing of project by exception.

✓ Project plan provides the yard-stick for measuring progress and evaluating resources performances

✓ project plan has build in flexibility in the form of floats, to navigate changes in the planned path for meeting fast changing environment.

✓ Project plan creates healthy environment. It promotes unity of purpose among functional diversities to make people time and cost conscious. It commits individuals to asks and motivates them to achieve challenging targets.

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Importance of planning , Scheduling and controlling projects

- **Schedule Benefits**

✓Schedule simplifying a project plan.

✓Schedule validates time objective.➔ work schedule shows the planned sequence of activities, data-wise.

✓Schedule aid in optimization of resource employed.

✓Schedule enables forecasting of input resources and earned value to indicate the pattern of requirement and the financial state of the project in terms of investment, expenditure, output and income.

✓Schedule brings out implication of time and resource constraints.

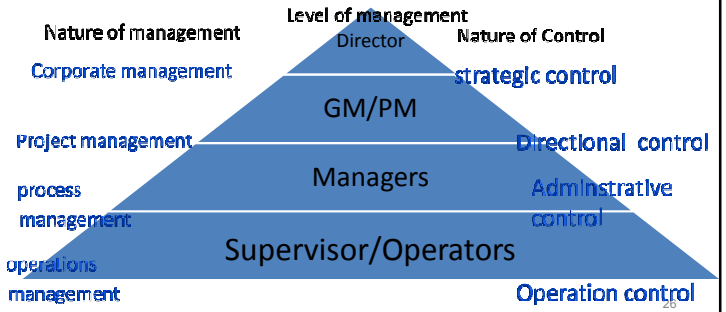
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Importance of planning , Scheduling and controlling projects

- **Control Benefit**

✓ The control system aids the management at various levels to perform its functions efficiently and effectively for achieving the overall project objectives.

✓ The benefits which can be derived at each level of management through an effective control system are;



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- Operational control at Supervisory Level

In improves productivity by;

➔ Minimize unproductive man hours
➔ Preventing wastage of materials
➔ Economizing plant and machinery utilization
➔ Reducing activity execution time

- Administrative control at managerial level: it assists in ensuring project organization efficiency and effectiveness by;

➔updating the work quantities status and determining the balance scope of work
➔analyzing project time status and its implication on project time objectives.
➔evaluating production cost status and forecasting future trends.
➔calculating income status and forecasting cash inflows
➔computing budget status and forecasting cash inflows
➔ Computing budgets status and analyzing the implication of variance of future expenditure.

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- Directional control at general manager's/ project manager's level

It helps in formulating and directing polices for achievement of project objectives

➔Analyzing project time cost behavior and making decisions on time saving when required

➔Reviewing project costs and profitability, and making profitability improvement decisions concerning wastage reductions through rigorous cost control, value engineering techniques, cost benefits analysis, workers incentive schemes and alternate methods of construction which cost less.

- Strategic control at corporate level

It provides information concerning corporate goals and assistance in formulating corporate strategies by;

➔Determining overall profitability
➔budgeting and allocating funds and resources.
➔ Updating the company's planning norms and unit rates for securing future works.

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Project work Breakdown

➔Project work-breakdown methodology enables splitting of the project work into hierarchical work-breakdown levels of;

- ✓sub-projects
- ✓tasks
- ✓Work packages
- ✓Activities

➔Each activity represents an identifiable lower-level job which consumes time, and possibly resource.

❖Construction projects are best organized by tasks into task responsibility centers. They are best managed by work packages and best planned and mentored by activities.

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Project work Breakdown levels

➔the project work-breakdown process involves breaking down of the project work into manageable parts arranged in a hierarchical order till the desired level is reached.

➔work-breakdown levels;

- ✓ Sub-project level-Mini project/task groups
- ✓ Tasks level-a task is an identifiable and deliverable major work, is used in the project-summary plan, the design-Preparation plan and the contract tendering plan.
- ✓ Work package level-Each work package contains a sizable, identifiable, measurable, costable and controllable package of work. In the project master plan or the contracted works-plan, each work package is assigned its performance objective. These are generally stated in terms of its completion period, standard cost and resource productivity standard.
- ✓ Activity level
- ✓ Operational level

➔the work breakdown structure of a project forms the basis for listing of activities, modification of systems, storing data by hierarchy levels, structuring of work organization and managing similar-scope multi-projects

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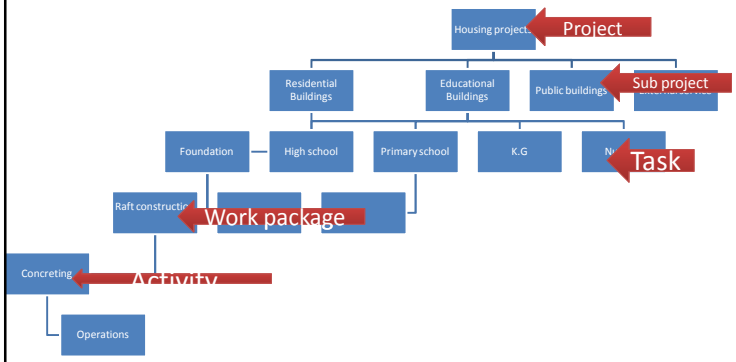
Example (2000 Housing Unit project)

Scope of Work

➔the project work included construction of 2000 residential apartments, educational buildings, public buildings, a civic center, connected external utility services and landscaping. The total value of contracted work was approximately US$160 million and the project was contracted for completion in 36 months.

➔[the residential accommodation was of precast concrete construction. The 2000 apartments were grouped into residential building consisting of 334 identical modules with each containing six flats. The precast production and reaction was geared to achieve a peak of five flats per working day.]

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Example, Operation involved in concreting are;

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

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Determining activities involved

➔The commonly used methods for determining activities depending on the nature of the project;

Nature of Activity	Method used
Construction activities	Work-breakdown structure
Functional activities	Task Matrix
Repetitive activities	Structure and Matrix Combine
Building construction activities	Specification standards(e.g.. Applicable relevant doc.)

1. Work-breakdown structure

➔ The various construction activities can be identified by systematically developing a work-breakdown structure, as indicated in the previous slide!

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2. Task Matrix

➔The task matrix method is generally used for determining fu…e Vs F…

Task code	Task description	Activities with duration in the month			
		Accomplishing	Designing	Contracting	Execution
A	Land procurement and survey	1	-		

3. Work Breakdown and task matrix for Repetitive works

➔…work…ties in…

Si.No.	Activity	Activities with duration in the month			
		Primary School	High school	K.G School	Nursery School
1	Excavation and Footing	1	-		

4…

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Assessing Activity Duration

➔Duration of an activity is defined as the expected economical transaction time. The estimation of time is based upon the current practices carried out in an organized manner under the normal prevailing conditions, and its assessment is done preferably, by the person responsible for its performance.

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

➔Under normal prevailing site condition using economical resource

➔activity is Performed in an organized manner ➔ breaking down activity into elements, matching optimum resource for each elements, laying down a systematic way method of execution, specifying objectives and assigning responsibility .

➔Responsible person➔ this makes the duration estimate realistic and meaningful.

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➔the construction activity accomplishment process combines resources: men, materials, and machinery. the first step in duration estimation is the methodology to be used for transforming these input resources into the desired activity. ➔ the method of choosing and combining these resource may vary!

Duration Estimation methods

1. one time estimate

➔the estimation of duration is based on one of the following;

i. Planning data
ii. Past experience or execution of a similar project
iii. Average time assessed by a group of executives.

2. Three time estimate

➔ When the exact duration of an activity, like research and development, is not certain, the three-times estimate is used to compute its expected duration.

➔ Application in construction projects -->in certain areas of construction projects where time is the main criterion and the resources employed are of secondary consideration;

Te=[To+4Tm+Tp]/6 ➔To, everything goes extremely well with no delays, Tp everything goes wrong

➔ Application in Construction Projects

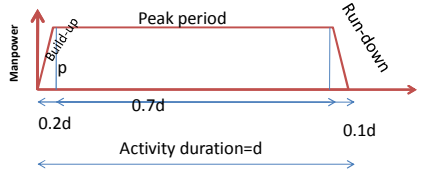
1. Planning of the projects especially, at the feasibility stage
2. The Skelton networks enclosed with the tender documents.
3. The contracted works, where time is the main consideration for management
4. The complex structures, where the exact duration estimate is difficult to assess.

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3. Trapezoidal distribution estimate

➔in practice, the profile of most activities takes the shape of trapezoidal distribution. The build-up and rundown phase can be expressed in terms of total activity duration. Assuming build-up and rundown time as 20% & 10% respectively of the total duration.

Total man days=[0.2d/2]xP +0.7dxP+ [0.1d/2]xP=0.85dp,
Duration d=[Total man-days/(0.85p)], in days



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Duration Estimation procedure

➔Estimating the quantity of work
➔Deciding the labor and material constants
➔Assessing the effective activity-wise employment of resource
➔Estimate the activity completion period

Completion period=Quantity of work/[output per unit of resource **X** resource earmarked]

$$t=Q/(n_x p)$$

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Chapter three Network analysis

➔CPM-> is best suited for activities with deterministic single-time duration
➔PERT->useful for project feasibility reports or tasks involving uncertainties.
➔PN->commonly used technique for time planning of construction projects.

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CPM Network analysis Fundamentals

Network elements

- Event or Milestone
  - –A point in time when certain conditions have been fulfilled, such as the start or completion of one or more activities
  - –Unlike an activity, does not consume time or resources
  - –Hence, expresses a state of being
  - –Activities take place between events
- Activity
  - –An item of work that consumes time and resources to produce some result

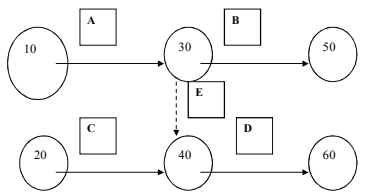
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Dummy Activity

- *This activity does not involve consumption of resources, and therefore does not need any time to be 'completed'.*
- *It is used to define interdependence between activities and included in a network for logical and mathematical reasons as will be shown later.*

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Illustration of event, activity, and dummy activity



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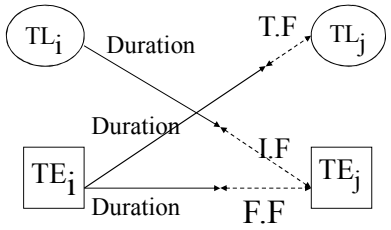
- Critical Path
  - The series of activities all of which must finish on time for the whole project to finish on time
  - Sometimes described as the longest path through a network, hence the shortest project time
  - A critical path has zero float
  - A critical path assumes that the network logic is sound

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- Float or Slack Time
  - The additional time available to complete a non-critical activity
- Leads and Lags
  - An imposed modification of the logical relationship between activities
  - To accelerate or delay the apparent natural order

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Illustration for TF, IF, and FF calculation



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Total Float

- *Total Float in an activity (i,j)* [TF(i,j)]
- Total float is the amount of time by which the start of an activity may be delayed without causing a delay in the completion of the project. This is calculated as (TF(i,j) = [LST(i,j)]– [EST(i,j)]) or ([LFT(i,j)]– [EFT(i,j)])

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Free Float

- Free float is the amount of time by which the start of an activity may be delayed without delaying the start of a following activity.
- Free Float = (Earliest start time of the following activity – Duration of the activity – Earliest start time of the activity) that is Free Float = TEj- TEi -D

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Independent Float

- Independent float is the amount of time by which the start of an activity may be delayed without affecting the preceding or the following activity.
- Independent Float = Earliest date for succeeding event – Latest date of preceding event – Activity duration that is Independent Float= TEj- TLi-D

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Network Preparation

➔ tabulate the network logic➔ drawing the arrow diagrams step-by-step.

Logic activity can be tabulated as

-> which activity/ies preceded & Succeed this activity?

->Are there any logical constraints imposed on this activity?

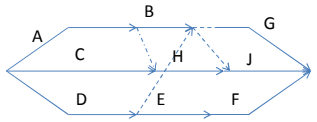
->Is it the final activity?

Example

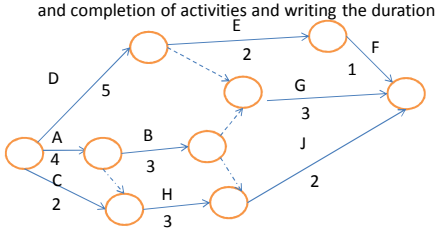
Activity	Preceding	Succeeding	Remarks
A	-	B,H	
B	A	G,J	
C	-	H	
D	-	E,G	
E	D	F	
F	E	-	Last activity
G	B,D	-	Last activity
H	A,C	J	
J	B,H	-	Last activity

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Logic diagram of activities

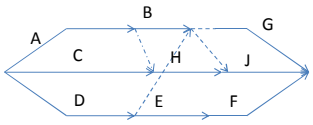


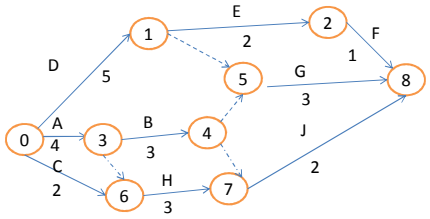
➔Rearrange to avoid crossing of arrows, inserting events to mark the start and completion of activities and writing the duration of each activity.



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Numbering Events





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Event Timings, Activity Timings and Associated Terms

- ***Start and finish times***
- *Earliest Start Time of an activity (i,j)* [EST(i,j)]
- This is the earliest that the activity (*i,j*) can be started, i.e., all the necessary preconditions are met.
- *Earliest Finish Time of an activity (i,j)* [EFT(i,j)]
- This is the earliest that an activity can be completed. Mathematically, the relationship can be expressed as
- EFT (i,j)= EST(i,j) + D(i,j)

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- *Latest Finish Time of an activity (i,j)* [LFT(i,j)]
  - the latest time that an activity needs to be completed in order that there is no delay in the project completion.
- *Latest Start Time of an activity (i,j)* [LST(i,j)]
  - the latest time when an activity must be started, in order that there is no delay in the project completion.

LST(i,j) = LFT(i,j) – D(i,j)

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Path and critical path

- Any series of activities connecting the starting point to the finishing point can be said to define a 'path' and indeed in a project having several activities, several such 'paths' can be identified.
- Among these paths, the 'critical path' is defined as one that gives the longest time of completion (of the project), which also defines the shortest possible project time.

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Forward and Backward Pass

- The forward pass moves from the 'start' node towards the 'finish' node, and basically calculates the earliest occurrence times of all events.
- Considering that the project starts at time zero, the earliest occurrence time at each node is found by going from node to node in the order of increasing node numbers keeping in mind the logical relationships between the nodes as shown by the connecting arrows.
- The earliest occurrence time for any node can be estimated from the (maximum) time taken to reach that node from the different incoming arrows.

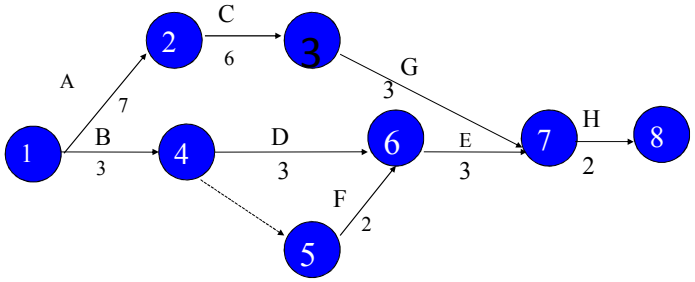
55

EXAMPLE

Task ID	Duration	Dependency
A	7	
B	3	
C	6	A
D	3	B
E	3	D,F
F	2	B
G	3	C
H	2	E,G

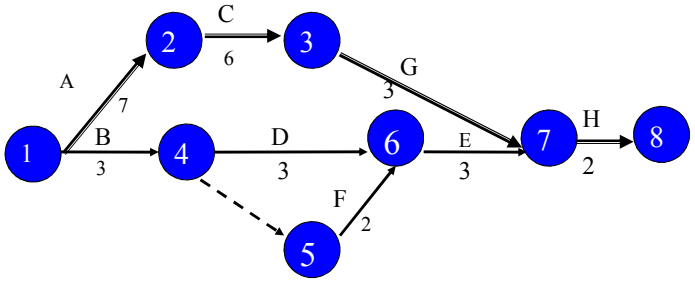
56

Network of the example



57

Network of the example



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Computations

Act.	Duration	EST	EFT	LST	LFT	TF
A	**7**	**0**	**7**	**0**	**7**	**0**
B	3	0	3	7	10	7
C	**6**	**7**	**13**	**7**	**13**	**0**
D	3	3	6	10	13	7
E	3	6	9	13	16	7
F	2	3	5	11	13	8
G	**3**	**13**	**16**	**13**	**16**	**0**
H	**2**	**16**	**18**	**16**	**18**	**0**

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Lecture-3 /4R/

- ✓Project Network Analysis (part II PERT & PNA)
- ✓Project Work Scheduling

Date 31/03/2011

Desalegn G.

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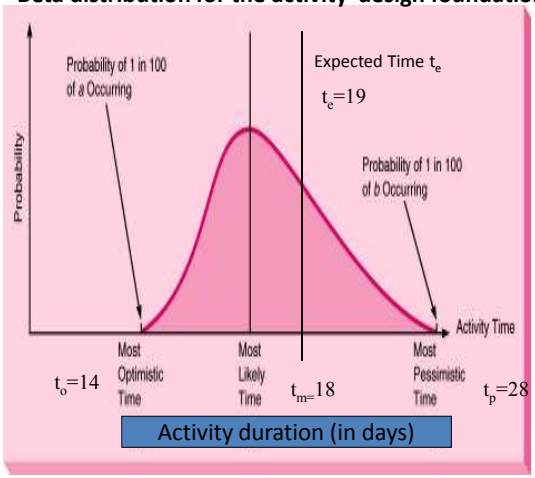
PERT

Example of three time estimate

- For an activity "design foundation"
  - the optimistic time = 14 days
  - the most likely time = 18 days and
  - the pessimistic time estimates = 28 days
- The PERT technique assumes that the three time estimates of an activity are random variables and the frequency distribution of duration of an activity takes the shape of Beta distribution

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Beta distribution for the activity 'design foundation'



62

- The average or expected time it is given by
- $t_e = (t_o + 4t_m + t_p)/6$
- For the case of 'design foundation', t_e can be worked out to be 19 days [(14 + 4 x18 + 28)/6].
- The fact that $t_e > t_m$ in this case, is a reflection of the extreme position of t_p and the asymmetry in the Beta distribution, even though computationally the weights given to t_o and t_p is the same.

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- There has been a lot of criticism on the approach of obtaining three ''valid'' time estimates to put into the PERT formulas.
- It is often difficult to arrive at one activity-time estimate; three subjective definitions of such estimates do not help the matter (how optimistic and pessimistic should one be).
- Nevertheless, the three time estimate also provides the advantages of ascertaining the variability or uncertainty associated with a particular set of estimate.

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- For example, suppose we have two sets of estimate provided by the different estimator for the same 'design foundation' activity.
- In order of (t_e, t_m,t_p), let the first set of estimate (14, 18, 28) and the other set of estimates be (17, 18, 25).
- There is large variability in the estimates of first estimator compared to the second one, even though the expected or average activity duration turns out to be 19 in both the cases (verify!!!).

65

- In order to measure the uncertainty associated with the estimate of duration of an activity, the standard deviation (St) and the variance Vt are determined, which in PERT are defined as:
- $S_t = (t_p - t_o)/6$ and
- $V_t = (S_t)^2$
- The formula for S_t indicates that it is one sixth of the difference between the two extreme time estimates.

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- Further, the greater the uncertainty in time estimates, the greater the value of (t_p-t_o), and the more spread out will be the distribution curve.
- A high S_t represents a high degree of uncertainty regarding activity times. In other words there is a greater chance that the actual time required to complete the activity will differ significantly from the expected time t_e.

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- For the two sets of estimate used in 'design activity', the St and Vt would be 2.33 days and 5.44 respectively for first set of estimates while 1.33 days and 1.77 are the corresponding values of St and Vt for the second set of estimates.

➔The expected length or duration of project Te is calculated by summing up the expected duration te's of activities on the critical path.

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- The critical path is determined following the forward pass and backward pass explained earlier.
- The variance associated with the critical path is the sum of variances associated with the activities on the critical path.

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➔In case, there is more than one critical path in a project network, then the path with the largest variance is chosen to determine the V_T and S_T. Mathematically,

- $T_e = \sum t_e$
- $V_T = \sum V_t$ and
- $S_T = \sqrt{V_T}$

70

- V_T and S_T represent variability in the expected project duration. The higher the V_T and S_T values, the more likely it is that the time required to complete the project will differ from the expected project length T_e.
- As was pointed earlier, t_o, t_m, and t_p are assumed to be a random variable following Beta distribution in the PERT technique.

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- Now that, t_e is the weighted sum of t_o, t_m, and t_p, it is also treated as a random variable. Since, T_e is the sum of t_e's it indeed is a random variable.
- The distribution of T_e follows normal distribution according to the Central Limit Theorem of statistics.

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- The behavior of normal distribution is well known and a number of assumptions can be drawn which could be useful to a planner or a project manager.
- For example, it is possible to compute the probability (index) of whether a project (or a key stage therein) will be completed on or before their schedule date(s).
- Of course, all this is possible under the assumption that the activities of the projects are statistically independent of each other.

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- Suppose, it is required to compute the probability of completing the project within a target duration of TD days.
- Now given the Te of the project it is possible to calculate the deviation of TD from Te in units of standard deviation.
- This is calculated from the normal distribution table. To adopt the table, a ratio called the standardised deviation or more often the normal deviate, Z, is derived. Z is defined as the ratio of the difference in TD and Te to S_T. Mathematically, $Z= (TD- Te)/ S_T$,

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$Z= (TD- Te)/ S_T$

➔Here Z is the number of standard deviations by which TD exceeds Te. Note that TD might be less than Te, in which case Z is negative. Now the probability measure the originally sought may be obtained by referring to the following table, extracted from a standard normal table:

Z	Probability of meeting Due Date
3.0	.999
2.8	.997
2.6	.995
2.4	.992
2.2	.986
2.0	.977
1.8	.964
1.6	.945
1.4	.919
1.2	.885

Z	Probability of meeting Due Date
1.0	.841
0.8	.788
0.6	.726
0.4	.655
0.2	.579
0.0	.500

75

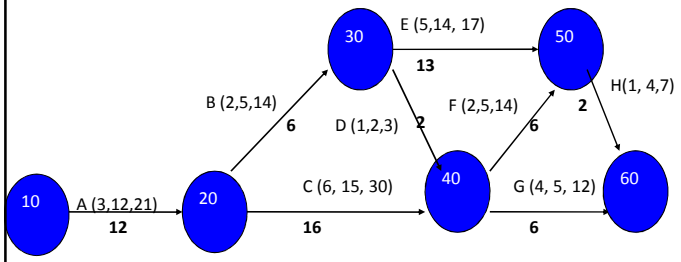
$Z= (TD- Te)/ S_T$

Z	Probability of meeting Due Date
-0.2	.421
-.4	.345
-.6	.274
-.8	.212
-1.0	.159
-1.2	.115
-1.4	.081
-1.6	.055
-1.8	.036
-2.0	.023

Z	Probability of meeting Due Date
-2.2	.014
-2.4	.008
-2.6	.005
-2.8	.003
-3.0	.001

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Example: PERT Diagram



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Expected duration, standard deviations and variances for activities

Activity Id	Duration (days)			Expected duration (days) $t_e=(t_o+4t_m+t_p)/6$	Standard deviation $S_t=(t_p-t_o)/6$	Variance $V_t=(S_t)^2$
	Optimistic duration t_o	Most likely duration t_m	Pessimistic duration t_p			
Col 1	Col 2	Col 3	Col 4	Col 5	Col6	Col 7
10-20	3	12	21	12	3	9
20-30	2	5	14	6	2	4
20-40	6	15	30	16	4	16
30-40	1	2	3	2	1/3	1/9
30-50	5	14	17	13	2	4
40-50	2	5	14	6	2	4
40-60	4	5	12	6	4/3	16/9
50-60	1	4	7	2	1	1

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Computation of early occurrence and late occurrence times

Node	Early occurrence time	Late occurrence time	Slack
10	0	12-12=0	0
20	0+12=12	Min of [(21-6)=15 and (28 - 16)=12]=12	0
30	12+6=18	Min of [(34-13)=21 and (28 - 2)=26]=21	3
40	Max of [(12+16)=28 and (18+2)=20]=28	Min of [(36-6)=30 and (34 - 6)=28]=28	0
50	Max of [(18+13)=31 and (28+6)=34]=34	36-2=34	0
60	Max of [(34+2)=36 and (28+6)=34]=36	36	0

79

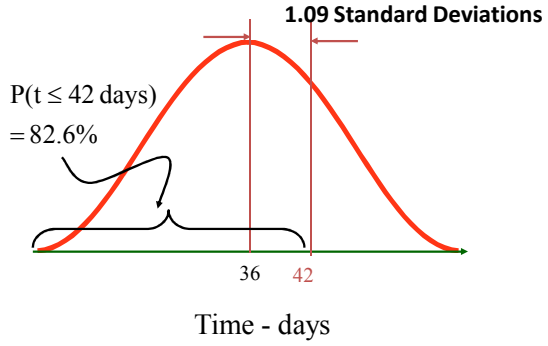
- Now, the problem of computing the probability of meeting target duration (TD), such as 42 days shown in the figure is quite simple. Since the total area under the normal curve is exactly one, the cross hatched area under the normal curve is directly the probability that the actual completion time, will be equal to, or less than, 42 days.
- In this case Z= (TD- TE)/ ST, = (42-36)/ 5.48 = 1.09 standard deviations.

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- In other words, the target duration TD is 1.09 standard deviations greater than the expected time TE=36 days.
- The equivalent probability P(Z=1.09) can be read off a normal probability distribution. This corresponds to a probability of 0.862 (86.2%)which implies that there is a 86.2% chance that the project will get completed within 42 days.

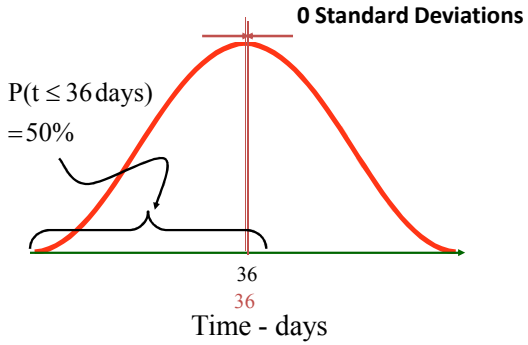
81

Meeting a Target Duration TD



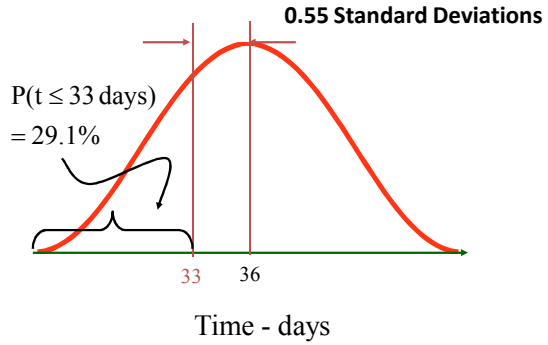
82

Meeting a Target Duration TD



83

Meeting a Target Duration TD



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- Assuming that time now is zero, one may expect this project to end at time 36 days (corresponding probability of achieving this target being 50%, verify!!! Hint: TD=36, T_E=36); and the probability that it will end on or before the target duration of 42, without expediting the project is approximately 86.2%.
- On the other hand, if one were to schedule towards TD= 33 days; herein TD<T_E; i.e. Z=-0.55 (Note the negative sign); the corresponding probability would be 0.291, which is really a very bleak situation.

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- In the above, the phrase 'without expediting' is very important.
- In certain projects schedules always may be met by some means or another,
- for example,
  - by changing the schedule,
  - by changing the project requirement,
  - by adding further personnel or facilities, etc.
- However, here it is implied that the probability being computed hereinabove is the one that the original schedule will be met without having to expedite the work in some way or another.

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- The feature in PERT on the computation of probability of completing the project in a particular duration is quite useful especially for negotiating the duration with an owner by the executing agency.
- For example, while agreeing on a particular duration, the executing agency would like to judge his chances on completing the project in that duration.

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- For being reasonably sure of a particular duration, he would like to attain a probability of more than 95%.
- Thus for the same example, suppose the executing agency is asked to provide the projected duration for the project, the agency would find out the duration corresponding to Z(P=0.95)= 1.65, thus the target duration for this case could be TD= TE + 1.65 x ST= 36 + 1.65 x 5.48= approximately 45 days. In other words, the executing agency would be quite confident of completing the project in 45 days.

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PRECEDENCE NETWORK ANALYSIS

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PRECEDENCE NETWORK

- it is AON diagram with activities on nodes or boxes and precedence relationship shown as arrow ➔but precedence network without arrows also is possible!
- numbering of activity also follows rules similar to that followed in PERT and CPM
- time estimate for the activity could be *one time estimate* or *three time estimate*
- But the *three time estimate* needs to be converted into single time before using in the network, by computing the expected time!

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PRECEDENCE NETWORK LAYOUT

- many variants of the boxes or nodes in a precedence network possible based on information the user desires
- For illustration, a typical box used for all the preceding examples
  - has been divided into three horizontal parts, *top*, *middle* and *bottom*
  - top & bottom are again divided vertically into three compartments, left, center and right
- Sample network diagram given in the following slide

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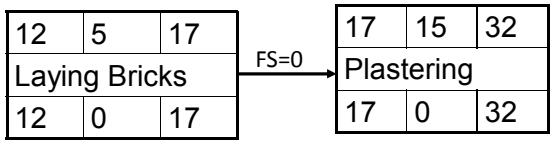
PRECEDENCE NETWORK

- Common type of relationship used in CPM and PERT
  - **FS – *Finish* to *Start*** relationship
- In reality, other relationships are possible, i.e.
  - **SS – *Start*** to ***Start***
  - **SF – *Start*** to ***Finish***
  - **FF – *Finish*** to ***Finish***
- Precedence networks incorporates the mentioned four types of relationships

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FS – Finish to Start relationship

- Task 'B' can't start unless Task 'A' is completed
- For (e.g.) consider a project with two tasks
  - Task 1 – Laying bricks
  - Task 2 – Plastering
  - Plastering can't start until laying bricks is complete (common dependency)
- Case 'a':

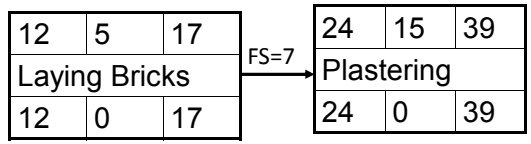


- There is no lead or lag
- Plaster commences after complete laying of bricks

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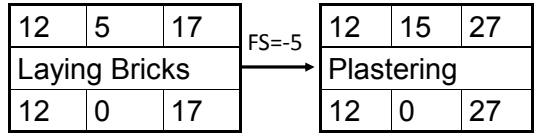
FS – Finish to Start relationship (contd.)

- Case 'b':



- There is a lead of 7 days
- Plaster commences 7 days after laying bricks

- Case 'c':



- There is a lag of 5 days
- Plaster commences 5 days before completion of laying bricks

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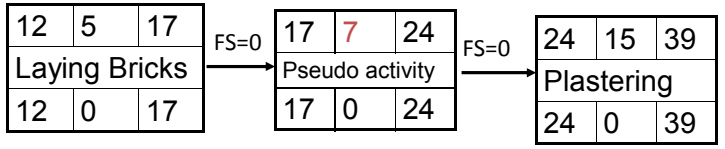
PRECEDENCE NETWORK (contd.)

- Lead – Lag factors portrayed in two ways:
  - lead-lag factors shown on arrow joining the two boxes
  - introduction of '***pseudo activity***' between the two activities
- Pseudo activity method similar to the one adopted in CPM, PERT
- But this method results in a lengthy network and increases the computational efforts

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FS – Finish to Start relationship **(pseudo activity)**

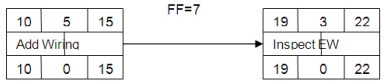
- Case 'b':
- Lead of 7 days described as a pseudo activity



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FF – Finish to Finish relationship

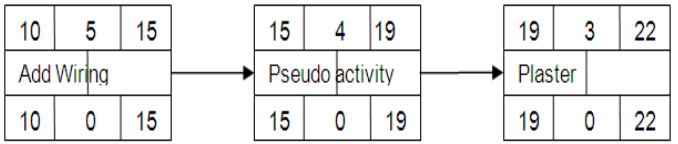
- Task 'B' can't finish unless Task 'A' finishes
- For (e.g.) consider a project with two tasks
  - Task 1 – Add wiring
  - Task 2 – Inspect electrical work
  - "Inspect electrical work" can't finish until "Add wiring" finishes
- Lead-Lag factors shown on the arrow



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FF – Finish to Finish relationship (contd.)

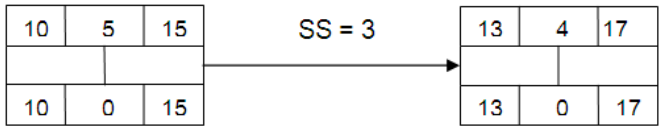
- represented using a pseudo activity



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SS – Start to Start relationship

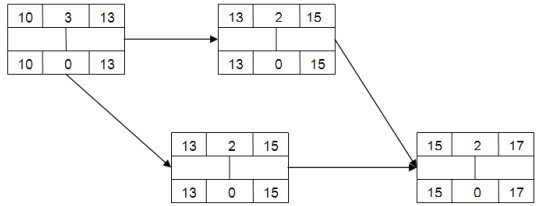
- Task 'B' can't start unless Task 'A' start
- For (e.g.) consider a project with two tasks
  - Task 1 – Pour foundation
  - Task 2 – Level concrete
  - "Level concrete" can't begin until "Pour foundation" begins
- Lead-Lag factors shown on the arrow



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SS – Start to Start relationship (contd.)

- Represented using two activities- preceding activity in two components and then proceeded
- disadvantage would be the additional list of activities and a lengthy network. Similar to approach used in PERT/ CPM in order to accommodate such type of relationships



100

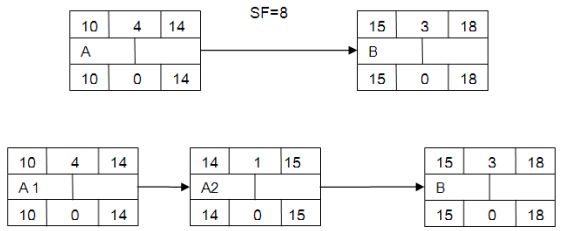
SF – Start to Finish relationship

- Task 'B' can't finish unless Task 'A' start
- SF dependency can be created between the task we want to schedule just in time (the predecessor) and its related task (the successor)
- If successor task updated also, it won't affect the scheduled dates of the predecessor task
- Can be used for just-in-time scheduling up to a milestone or the project finish date to minimize the risk of a task finishing late if its dependent tasks slip
- SF not commonly used in precedence networks, but included here to have a complete discussion.

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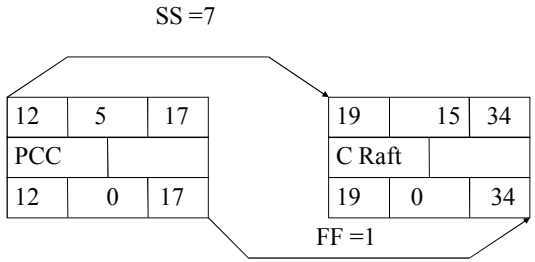
SF – Start to Finish relationship (contd.)

- the two ways of representing the SF activity are as follows:



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Illustration of dual relationship in precedence network



- more than one type of relationships has been assigned between two activities in the given network, which is an additional advantage of precedence network

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Important Points

- Determination of critical path is not that simple as compared to network techniques such as PERT and CPM.
- The process is identical if only FS relationship is used in the network.
- If the activities have SS, FF, and SF relationship in the network, then determining critical path becomes difficult especially if manual computations are performed.

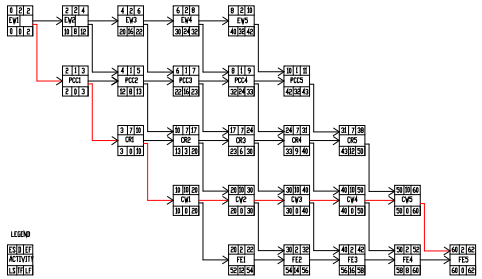
104

Important Points

- Further, in precedence network, the activities on critical path may not be connected clearly in a sequence!
- Also, the total slack definition adopted (LS-ES or LF-EF) for networks such as PERT/CPM may or may not give same values!

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SAMPLE PRECEDENCE NETWORK (contd.)



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PRECEDENCE NETWORK LAYOUT (contd.)

- top left compartment – *earliest start time*
- top centre compartment – *activity duration*
- top right compartment – *earliest finish time*
- middle left portion – *activity description*
- middle right – *node number*
- bottom left compartment – *latest start time*
- bottom centre compartment – *total float*
- bottom right compartment – *latest finish time*

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PRECEDENCE NETWORK PROCEDURE

- For the above sample example the Forward and Backward passes is computed in similar manner as CPM & PERT since only FS type relationship is used!
- Critical path(s) is (are) identified next
- This has activities with zero float logically linked between the start activity and finish activity
- Float is the difference between the late start and early start

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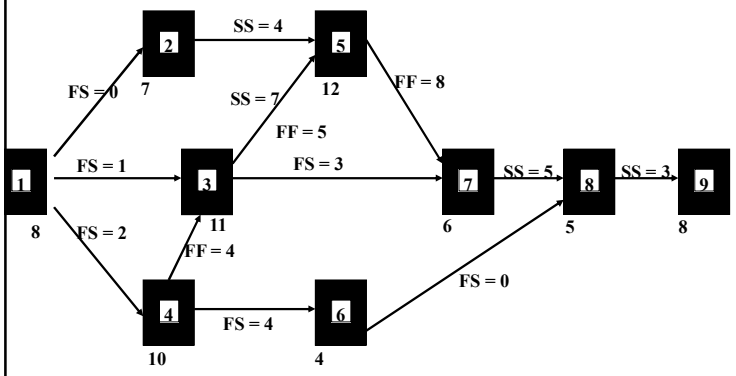
Explanation of determination of early start and early finish activity times

Node	Activity	Duration	EST	Remarks	EFT	Remarks
10	EW1	2	0	0 start activity, $EST_{10}=0$	2	$EFT_{10}=EST_{10}+d_{10}$
20	EW2	2	2	$EST_{20}=EFT_{10}+FS_{10-20}$ Hence, $EST_{20}=2+0$	4	$EFT_{20}=EST_{20}+d_{20}$ Hence, $EFT_{20}=2+2$

Explanation of determination of late finish and late start activity times

Node	Activity	Duration	LFT	Remarks	LST	Remarks

EXAMPLE



FORWARD PASS

Node	Duration dur_i	EST_i	Remarks	EFT	Remarks
1	8	0	0,Start Activity $EST_1 = 0$	8	$EFT_1 = EST_1 + dur_1$ $= 0 + 8 = 0$
2	7	8	$EST_2 = EFT_1 + FS_{1-2}$ $= 8 + 0 = 8$	10	$EFT_2 = EST_2 + dur_2$ $= 8 + 7 = 15$
4	10	10	$EST_4 = EFT_1 + FS_{1-4}$ $= 8 + 2 = 10$	20	$EFT_4 = EST_4 + dur_4$ $= 10 + 10 = 20$
3	11	13 (Max of 9,13)	$EST_3 = EFT_1 + FS_{1-3}$ $= 8 + 1 = 9$ $EST_3 = EFT_4 + FF_{3-4}\text{-}dur_3$ $=20 + 4\text{-}11=13$	24	$EFT_3 = EST_3 + dur_3$ $= 13 + 11 = 24$

FORWARD PASS

Node	Duration dur_i	EST_i	Remarks	EFT	Remarks
5	12	20 (Max of 12, 20,17)	$EST_5 = EST_2 + SS_{2-5}$ = 8 + 4 = 12 $EST_5 = EST_3 + SS_{3-5}$ =13 + 7=20 $EST_5 = EFT_3 + FF_{3-5} - dur_5$ =24 + 5-12=17	32	$EFT_5 = EST_5 + dur_5$ = 20 + 12 = 32
6	4	24	$EST_6 = EFT_4 + FS_{4-6}$ = 20 + 4 = 24	28	$EFT_6 = EST_6 + dur_6$ = 24 + 4 = 28

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Node	Duration dur_i	EST_i	Remarks	EFT	Remarks
7	6	34 Max of (27,34)	$EST_6 = EFT_3 + FS_{3-7}$ = 24 + 3 = 27 $EST_6 = EFT_5 + FF_{5-7} - dur_7$ =32 + 8-6=34	40	$EFT_7 = EST_7 + dur_7$ = 34 + 6 = 40
8	5	39 Max of (28, 39)	$EST_8 = EFT_6 + FS_{6-8}$ = 28 + 0 = 28 $EST_8 = EST_7 + SS_{7-8}$ =34 +5 = 39	5	$EFT_8 = EST_8 + dur_8$ = 39 + 5 = 44
9	8	42	$EST_9 = EST_8 + SS_{8-9}$ =39 +3 = 42	50	$EFT_9 = EST_9 + dur_9$ = 42 + 8 = 50

114

BACKWARD PASS

Node	Duration dur_i	LFT_i	Remarks	EFT	Remarks
9	8	50		42	
8	5	44	$LFT_8 = LST_9 - SS_{8-9} + dur_8$ =42 -3 +5 = 44	39	44-5 =39
7	6	40	$LFT_7 = LST_8 - SS_{7-8} + dur_7$ =39 -5 +6 = 40	34	40-6= 34
6	4	39	$LFT_6 = LST_8 - FS_{6-8}$ =39-0 =39	35	39-4 =35
5	12	32	$LFT_5 = LFT_7 - FF_{5-7}$ =40-8 =32	20	32-12 =20

115

BACKWARD PASS

Node	Duration dur_i	LFT_i	Remarks	EFT	Remarks
3	11	24 Min (24, 27, 31)	$LFT_3 = LST_5 - SS_{3-5} + dur_3$ =20-7+11 = 24 $LFT_3 = LFT_5 - FF_{3-5}$ = 32 – 6 = 27 $LFT_3 = LST_7 - FS_{3-7}$ =34-3 =31	13	24-11=13
4	10	20 Min (20,31)	$LFT_4 = LFT_3 - FF_{3-4}$ = 24 – 4 = 20 $LFT_4 = LST_6 - FS_{4-6}$ =35-4 =31	10	20-10= 10

116

BACKWARD PASS

Node	Duration dur_i	LFT_i	Remarks	EFT	Remarks
2	7	23	$LFT_2=LST_5-SS_{2-5}+dur_2$ =20-4+7 = 23	16	23-7=16
1	8	8 Min (16,12, 8)	$LFT_1=LST_2-FS_{1-2}$ =16-0 =16 $LFT_1=LST_3-FS_{1-3}$ =13-1 =12 $LFT_1=LST_4-FS_{1-4}$ =10-2 =8	0	8-8 = 0

117

CRITICAL PATH is the path in which

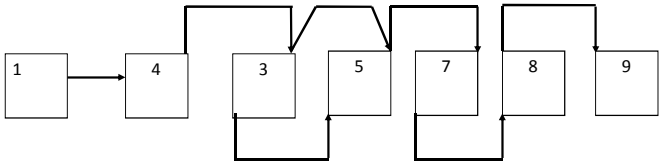
- total float = 0
- is given by 1 – 4 – 3 – 5 – 7 – 8 – 9

Calculation of floats of activities

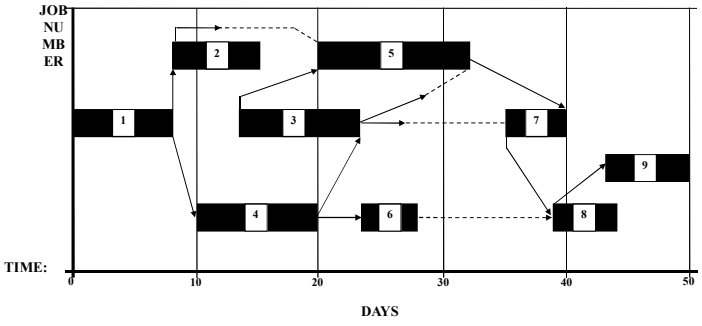
Node	EST	EFT	LST	LFT	Float (LST-EST)
1	0	8	0	8	0
2	8	15	16	23	8
3	13	24	13	24	0
4	10	20	10	20	0
5	20	32	20	32	0
6	24	28	35	39	11
7	34	40	34	40	0
8	39	44	39	44	0
9	42	50	42	50	0

118

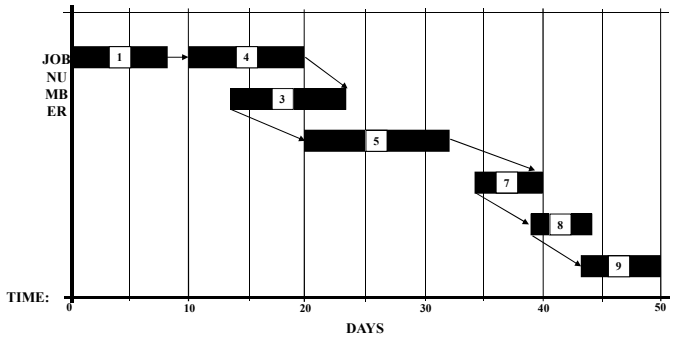
Critical Path



119



120



121

PRECEDENCE NETWORK PROCEDURE (contd.)

- The procedure of forward and backward passes change if there are relationships of type FF and SF
- In the forward pass
  - ✓ activity start time is calculated with FS and SS relationships
  - ✓ finish time is calculated with FF and SF relationship, along with the activity duration
- If the early start and early finish so calculated differ by more than the activities duration then the activity is split according to the rules outlined in the algorithm!

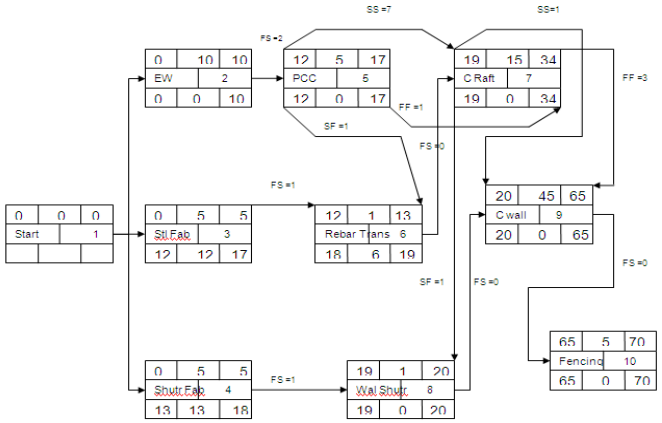
122

Example – PRECEDENCE NETWORK PROCEDURE

- For illustrating the set of rules used in forward pass and backward pass for illustrating activity time computations and critical path determination, we take up the following network
- relationships between different activities are self explanatory

123

Example of a precedence network with FS, FF, SS, and SF relationships



124

FORWARD PASS EXPLANATION FOR THE NETWORK

- We start from the first node and move to the last node
- Node 1
  - EST (start) is set to 0 to commence the forward pass computations
  - However, any other number can also be assigned for this purpose
  - Since 'start' is not consuming any time, also the EFT of node 1 = 0
  - EFT = EST + Duration (0) = 0 + 0 = 0
- Node 2
  - EST2 = EFT1 + lead lag factor = 0 + 0 = 0
  - EFT2 = EST2 + duration = 0 + 10 = 10
- Node 3
  - EST3 = EFT1 + lead lag factor = 0 + 0 = 0
  - EFT3 = EST3 + duration = 0 + 5 = 5

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FORWARD PASS EXPLANATION FOR THE NETWORK (contd.)

- Node 4
  - EST4 = EFT1 + lead lag factor = 0 + 0 = 0
  - EFT4 = EST4 + duration = 0 + 5 = 5
- Node 5
  - Relationship with predecessor – FS
  - EST5 = EFT2 + lead lag factor = 10 + 2 = 12
  - EFT5 = EST5 + duration = 12 + 5 = 17

126

FORWARD PASS EXPLANATION FOR THE NETWORK (contd.)

- Node 6
  - It has 2 predecessors and hence we have to compute EST for each
  - Relationship with predecessor (3) – FS
  - EST6 = EFT3 + lead lag factor = 5 + 1 = 6
  - Relationship with predecessor (5) – SF
  - EST5 = EST5 + lead lag factor – duration = 12 + 1 - 1 = 12
  - We select the Max(EST) which we obtain from the predecessor 5
  - EFT6 = EST6 + duration = 12 + 1 = 13

127

FORWARD PASS EXPLANATION FOR THE NETWORK (contd.)

- Node 7
  - It has 2 predecessors and 3 relationships hence we have to compute EST for each
  - Relationship with predecessor (5) – SS
  - EST7 = EST5 + lead lag factor = 12 + 7 = 19
  - Relationship with predecessor (5) – FF
  - EST7 = EFT5 + lead lag factor – duration = 17 + 1 - 15 = 3
  - Relationship with predecessor (6) - FS
  - EST7 = EFT 6 + lead lag factor = 13 + 0 = 13
  - We select the Max(EST) which we obtain from the predecessor 5
  - EFT6 = EST6 + duration = 19 + 15 = 34

128

FORWARD PASS EXPLANATION FOR THE NETWORK (contd.)

- Node 8
  - It has 2 predecessors and 2 relationships hence we have to compute EST for each
  - Relationship with predecessor (4) – FS
  - EST8 = EFT4 + lead lag factor = 5 + 1 = 6
  - Relationship with predecessor (7) – SF
  - EST8 = EST7 + lead lag factor – duration = 19 + 1 - 1 = 19
  - We select the Max(EST) which we obtain from the predecessor 7
  - EFT6 = EST6 + duration = 19 + 1 = 20

129

FORWARD PASS EXPLANATION FOR THE NETWORK (contd.)

- Node 9
  - It has 2 predecessors and 3 relationships hence we have to compute EST for each
  - Relationship with predecessor (7) – SS
  - EST9 = EST7 + lead lag factor = 19 + 1 = 20
  - Relationship with predecessor (7) – FF
  - EST9 = EFT7 + lead lag factor – duration = 34 + 3 - 45 = - 8
  - Relationship with predecessor (8) - FS
  - EST9 = EFT8 + lead lag factor = 20 + 0 = 20
  - We select the Max(EST) which we obtain from the predecessors 7, 8
  - EFT6 = EST6 + duration = 20 + 45 = 65

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FORWARD PASS EXPLANATION FOR THE NETWORK (contd.)

- Node 10
  - EST10 = EFT9 + lead lag factor = 65 + 0 = 65
  - EFT10 = EST10 + duration = 65 + 5 = 70

131

BACKWARD PASS EXPLANATION FOR THE NETWORK

- We start from the last node and move to the first node
- Node 10
  - LFT of node 10 is set to EFT 10 to commence the backward pass computations
  - LST = LFT - Duration = 70 – 5 = 65
- Node 9
  - Relationship with successor (10) – FS
  - LFT 9 = LST10 - lead lag factor = 65 – 0 = 65
  - LST 9 = LFT9 - duration = 65 - 45 = 20
- Node 8
  - Relationship with successor (9) – FS
  - LFT 8 = LST9 - lead lag factor = 20 – 0 = 20
  - LST 8 = LFT8 - duration = 20 - 1 = 19

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BACKWARD PASS EXPLANATION FOR THE NETWORK (contd.)

- Node 7
  - It has 2 successors and 3 relationships hence we have to compute LFT for each
  - Relationship with successor (9) – SS
  - LFT 7 = LST9 – lead lag factor + duration = 20 -1 + 15 = 34
  - Relationship with successor (9) – FF
  - LFT 7 = LFT5 - lead lag factor = 65 - 3 = 62
  - Relationship with successor (8) - SF
  - LFT 7 = LST 8 - lead lag factor + duration = 20 – 1 + 15 = 34
  - We select the Min(LFT) which we obtain from the successors 8, 9
  - LST 7 = LFT7 - duration = 34 - 15 = 19

133

BACKWARD PASS EXPLANATION FOR THE NETWORK (contd.)

- Node 6
  - It has 1 successor
  - Relationship with successor (7) – FS
  - LFT 6 = LST7 – lead lag factor = 19 - 0 = 19
  - LST 6 = LFT6 - duration = 19 - 1 = 18
- Node 5
  - It has 2 successors and 3 relationships hence we have to compute LFT for each
  - Relationship with successor (7) – SS
  - LFT 5 = LST7 – lead lag factor + duration = 19 -7 + 5 = 17
  - Relationship with successor (7) – FF
  - LFT 5 = LFT7 - lead lag factor = 34 - 1 = 33
  - Relationship with successor (6) - SF

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BACKWARD PASS EXPLANATION FOR THE NETWORK (contd.)

- Node 5 (contd.)
  - LFT 5 = LST 6 - lead lag factor + duration = 19 – 1 + 5 = 23
  - We select the Min(LFT) which we obtain from the successor 7
  - LST 6 = LFT6 - duration = 17 – 5 = 12
- Node 4
  - Relationship with successor (8) – FS
  - LFT 4 = LST8 - lead lag factor = 19 – 1 = 18
  - LST 4 = LFT4 - duration = 18 - 5 = 13
- Node 3
  - Relationship with successor (6) – FS
  - LFT 3 = LST6 - lead lag factor = 18 – 1 = 17
  - LST 3 = LFT3 - duration = 17 - 5 = 12

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BACKWARD PASS EXPLANATION FOR THE NETWORK (contd.)

- Node 2
  - Relationship with successor (5) – FS
  - Relationship with successor (5) – FS
  - LST 2 = LFT2 - duration = 10 - 10 = 0
- Node 1
  - Since it is a start dummy activity hence its LST
  - LFT = 0 which can be computed using
  - LFT 1 = LST2 - lead lag factor = 0 – 0 = 0
  - LFT 1 = LST3 - lead lag factor = 12 – 0 = 12
  - LFT 1 = LST4 - lead lag factor = 13 – 0 = 13
  - Choose the Min(LFT)
  - LST1 = LFT1 – duration = 0 – 0 = 0

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conclusion

- Evident from the above example that manual calculations are tedious when there are relationships other than FS in precedence networks

Total slack / float for each activity has been computed in the figure using the formulae

- TF = LST – EST
- TF = LFT – EFT

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FORWARD PASS

Node	Activity	Duration dur_i	EST_i	Remarks	EFT	Remarks
1	Start	0	0	0,Start Activity $EST_1 = 0$	0	$EFT_1 = EST_1 + dur_1$ $= 0 + 0 = 0$
2	EW	10	0	$EST_2 = EFT_1 + FS_{0-1}$ $= 0 + 0 = 0$	10	$EFT_2 = EST_2 + dur_2$ $= 0 + 10 = 10$
3	StlFab	5	0	$EST_3 = EFT_1 + FS_{1-3}$ $= 0 + 0 = 0$	5	$EFT_3 = EST_3 + dur_3$ $= 0 + 5 = 5$
4	ShutrFab	5	0	$EST_4 = EFT_1 + FS_{1-4}$ $= 0 + 0 = 0$	5	$EFT_4 = EST_4 + dur_4$ $= 0 + 5 = 5$
5	PCC	5	12	$EST_5 = EFT_2 + FS_{2-5}$ $FS_{2-5} = 2$, $EST_5 = 12$	17	$EFT_5 = EST_5 + dur_5$ $= 12 + 5 = 17$

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FORWARD PASS (contd.)

6	Rebar Trans	1	12	Taking Max EST	13	$EFT_6 = EST_6 + dur_6$ $= 12 + 1 = 13$
7	CRaft	15	19	Taking Max EST	34	$EFT_7 = EST_7 + dur_7$ $= 19 + 15 = 34$
8	Wall Raft	1	19	Taking Max EST	20	$EFT_8 = EST_8 + dur_8$ $= 19 + 1 = 20$
9	C Wall	45	20	Taking Max EST	65	$EFT_9 = EST_9 + dur_9$ $= 20 + 45 = 65$
10	Fencing	5	65	$EST_{10} = EFT_{10} + FS_{1-10}$ $FS_{1-10} = 0$	70	EFT_{10} $= EST_{10} + dur_{10}$ $= 65 + 5 = 70$

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BACKWARD PASS

Node	Activity	Duration dur_i	LFT_i	Remarks	EFT	Remarks
10	Fencing	5	70	Taking LFT_{10} same as EFT_{10}	65	$LST_{10} = LFT_{10} – dur_{10}$ $= 70 - 5 = 65$
9	C Wall	45	65	$LFT_9 = LST_1 – FS_{9-10}$ $= 65 - 0 = 65$	20	$LST_9 = LFT_9 – dur_9$ $= 65 - 45 = 20$
8	Wall Raft	1	20	$LFT_8 = LST_9 – FS_{8-9}$ $= 20 - 0 = 20$	19	$LST_8 = LFT_8 – dur_8$ $= 20 - 15 = 19$
7	CRaft	15	34	Taking Min of all LFT's	19	$LST_7 = LFT_7 – dur_7$ $= 34 - 15 = 19$
6	Rebar Trans	1	19	$LFT_7 = LST_7 – FS_{6-7}$ $= 19 - 0 = 19$	18	$LST_6 = LFT_6 – dur_6$ $= 19 - 1 = 18$

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BACKWARD PASS (contd.)

5	PCC	5	17	Taking Min of all LFT's	12	$LST_5=LFT_5 - dur_5$ = 17- 5 = 12
4	ShutrFab	5	18	$LFT_4 = LST_8 - FS_{4-8}$ = 19- 1 = 18	13	$LST_4=LFT_4 - dur_4$ = 18- 5 = 13
3	StlFab	5	17	$LFT_3 = LST_6 - FS_{1-6}$ = 18- 1 = 17	12	$LST_3=LFT_3 - dur_3$ = 17- 5 = 12
2	EW	10	10	$LFT_2 = LST_5 - FS_{2-5}$ = 12- 2 = 10	0	$LST_2=LFT_2 - dur_2$ = 10- 10 = 0
1	Start	0	0	Taking Min of all LFT's	0	$LST_1=LFT_1 - dur_1$ = 0- 0 = 0

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CONCLUSION

- Precedence network is becoming popular these days in construction industry
- Most of the latest software's such as PRIMAVERA and MS PROJECT etc. are fast becoming a standard around the world are based on this type of network
- Of course Primavera and Microsoft project can also produce bar charts from the precedence networks automatically, if it is desired!!

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Project work scheduling

✓Scheduling using Bar Chart

✓Scheduling the Network Plan

✓LOB Method of scheduling for Repetitive projects

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Introduction

➔A *schedule* is a work programme, set date wise in a logical sequence; it is a time table for action. Time scheduling is the process of developing a work programme. It implies programming of the chosen *work plan* on a calendar basis and provides the base against which all progress is measured.

➔ The scheduling methodology varies with the planning techniques and the nature of the task to be performed. A tool containing the commonly used techniques for planning, scheduling and monitoring is indicated in the next slide.

Introduction

Sl.NO	Nature of the project	Planning	Scheduling	Monitoring	Displaying
1	Simple project/sub project (a)Non-repetitive work (b)Repetitive work	Bar Chart LOB	Bar Chart LOB	Bar Chart LOB	Bar Chart LOB/Bar chart
2	Complex sub-projects (a)Deterministic (b)Probabilistic	CPM PERT	Time scale Network >>	CPM	Bar Chart >>
3	Complex Projects (a)Non-repetitive W. (b)Repetitive work (c)Probabilistic	PNA PNA PERT	Bar Chart LOB Time Scale network	PNA LOB PERT	Bar Chart Bar Chart/LOB Bar Chart
4	Linear Projects	LPC	LPC	LPC	Bar chart/ LPC

CPM-Critical Path
PERT-Programme Evaluation and Review Techniques
PNA- Precedence Network Analysis
LOB-Line of Balance

LPC-Linear Programme Chart
BC-Bar Chart
TSN-Time Scale Network/Logic Bar Chart

Introduction

➔ the method of presentation of a schedule depends upon the scheduling techniques used.

➔Generally, all of them use time scale along the horizontal axis. This time scale mostly uses a “week” as the unit of time; these weeks then related to the calendar dates and months.

➔Each Scheduling Techniques has its own merits and demerits. But ultimately scheduling are best presented in the bar chart form for ease of comprehension and communication. These bar charts are supplemented with appropriate planning technique for monitoring the progress of the projects.

Introduction

➔Purpose of work scheduling

- ➔It simplifies the project plan
- ➔It validates the time objectives
- ➔It optimizes the resource employed
- ➔It forecasts the input resources, and predicts the output
- ➔It evaluates the implications of scheduling constraints

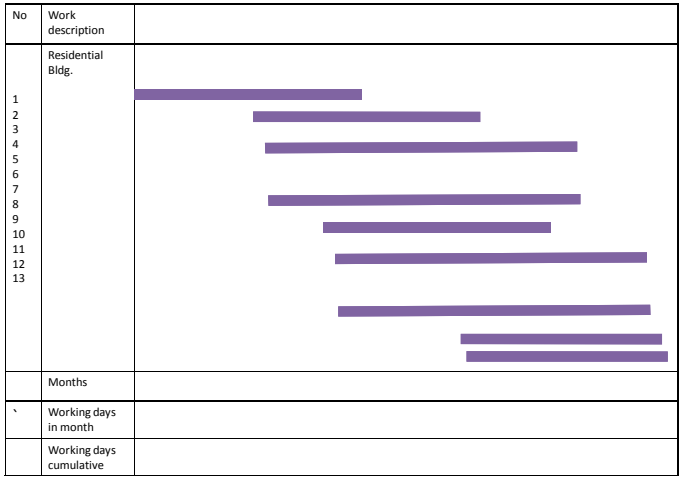
Bar Chart

➔In the bar chart method, works are first split in two activities. These activities are then listed in the order of construction priorities, generally on the left-hand side column, while the time scale is plotted horizontally on the top and/or bottom of the chart.

➔The bar against each activity represents its schedule of work

➔The start of the bar marks the commencement of the activity and the end of the bar its completion. The length of the bar on the calendar scale represents the duration of the activity.

Bar Chart



Bar Chart

➔Bar charts are easy to plot, comprehend and communicate, and are most appropriate for presentation of *schedules*. However, as *planning technique*, the bar chart is not suitable for complex projects due to the following reasons:

(a) It does not reflect the relationship between various activities which are a common feature of all complex projects.

(b) It cannot identify and highlight the emerging critical tasks needing special attention for preventing schedule slippages, time overruns, and other bottlenecks.

(c) In complex projects, time durations are often educated guesses. Any change in schedule or time duration would require a redrawing of the multi-task bar chart schedule.

➔ thus, it can be said that the bar chart format is most useful for presentation of schedules, but as a planning technique, it is not suitable for scheduling complex projects.

SCHEDULING THE NETWORK

- A scheduling aims at optimizing resources for completion of the project within stipulated time objectives. Resource optimization implies scheduling of resources according to the given pattern of their employment. Optimization is achieved by suitably adjusting the schedule of non-critical activities using available floats in such a manner that fluctuations from the desired pattern of resource utilization are minimized.

➔The scheduling of network plan involves the following steps;

- Outlining scheduling constraints(Time constraint or Resource Constraint)
- Identifying the floats of each activities to order of (ascending order of floats) sensitivity.
- Preparing the earliest start time(EST) schedule.
- Determining resource scheduling criteria
- Scheduling critical activities at their EST
- Scheduling non critical activities
- Optimizing other resources
- Validating time objective.

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RESOURCE LEVELING

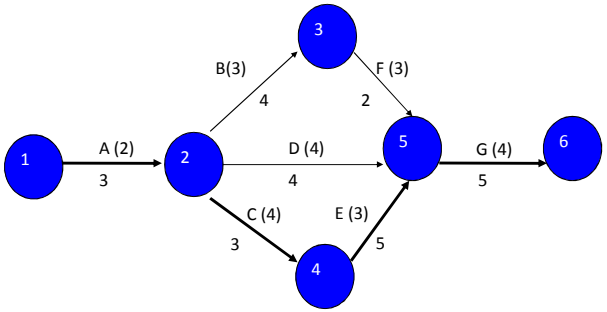
- In resource leveling, the constraint is the fixed project duration.
- That is the project must get completed by a fixed date.

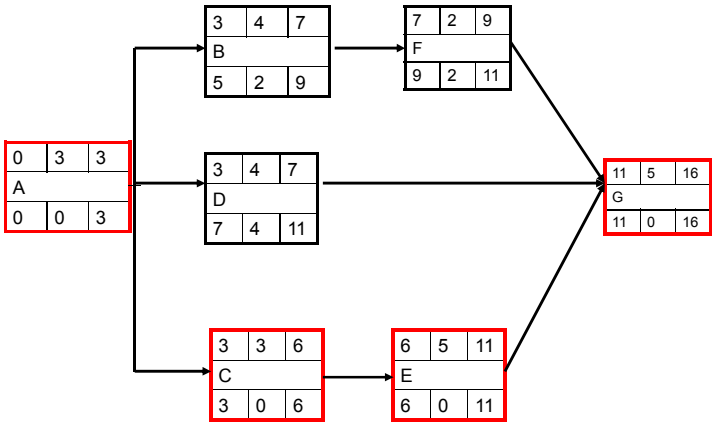
➔The attempt of such heuristic is to reduce peak requirement of resources and to smooth out period to period assignments.

  – Such problems are also referred to as ‘time limited resource considerations’ problems.

- The assessment of resources is done using resource loaded or resource aggregation chart.

Example to illustrate the concept of resource leveling.





- Let's assume that there are a total of 7 activities A to G in the example network.
- The duration of each of the activities are written below the arrow while the resource requirement of the activities is shown in the bracket adjacent to the activity name.
- For example, the duration for activity A is 3 days while the resource required by this activity is 2 units.
- The early start and late start time of events or nodes are also shown in the network from which the float available in a particular activity can be calculated thus critical activities can be identified.
- The critical path of the network is *1-2-4-5-6* and it consists of activities A, C, E, and G. The critical path is shown by bold arrows in the network.

Steps in Resource leveling

- The project network is prepared based on the data provided for each activity. Event times and activity times are computed as illustrated earlier thus total float is also computed for each of the activities.

➔ The list of activities are ranked in order of their EARLIEST START date (refer Table in the next slide).

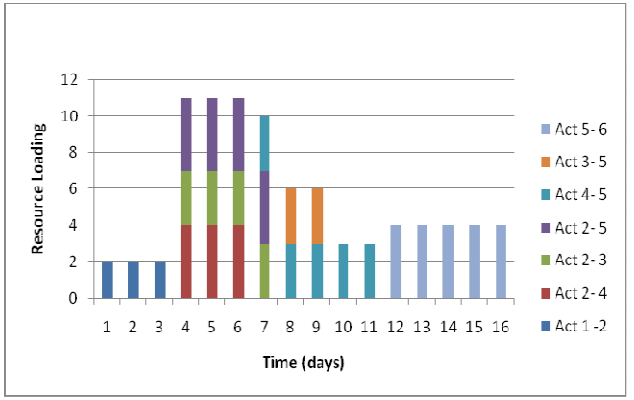
➔ The resources required on daily basis for each of the activities are summed up and shown in the form of a chart called resource aggregation or resource loading chart.

➔ Fig 3.2 shows resource loading chart based on the earliest start time of all the activities. The project takes a total of 87 man days to complete and the daily requirement varies from a minimum of 2 resources on days 1 to 3 to a maximum of 11 resources on days 4, 5, and 6.

Resource loading table showing daily requirement of workers based on EARLY START order

Act.	EST	Time	Res.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1-2	0	3	2	2	2	2													
2-4	3	3	4				4	4	4										
2-3	3	4	3				3	3	3	3									
2-5	3	4	4				4	4	4	4									
4-5	6	5	3							3	3	3	3	3					
3-5	7	2	3								3	3							
5-6	11	5	4												4	4	4	4	4
Total				2	2	2	11	11	11	10	6	6	3	3	4	4	4	4	4

Resource aggregation or resource loading chart based on early start.



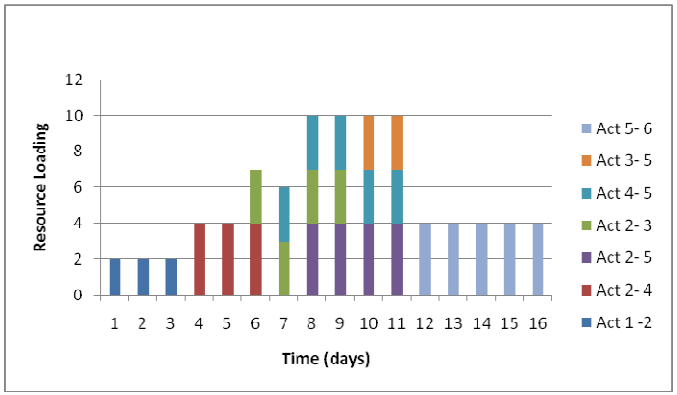
Steps in Resource leveling contd..

- Now the activities are ranked in order of their LATEST START DATE (refer Table below). It may be noted that the latest start date of an activity is the latest time of the finish event less the duration.
- Thus latest start times of activities 1-2, 2-4, 2-3, 4-5, 2-5, 3-5, and 5-6 are on days 0, 3, 5, 6, 7, 9 and 11 respectively in the ascending order.
- The resource loading chart shown in Fig below is prepared based on the ascending order of latest start time of each activity. It can be noticed that the requirement of resources varies from a minimum of 2 to a maximum of 10 resources.

Table 3.2 Resource loading table showing daily requirement of workers based on LATE START order

Act.	LST	T	Res	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1-2	0	3	2	2	2	2													
2-4	3	3	4				4	4	4										
2-3	5	4	3						3	3	3	3							
4-5	6	5	3							3	3	3	3	3					
2-5	7	4	4								4	4	4	4					
3-5	9	2	3										3	3					
5-6	11	5	4												4	4	4	4	4
Total				2	2	2	4	4	7	6	10	10	10	10	4	4	4	4	4

Resource aggregation or resource loading chart based on late start.



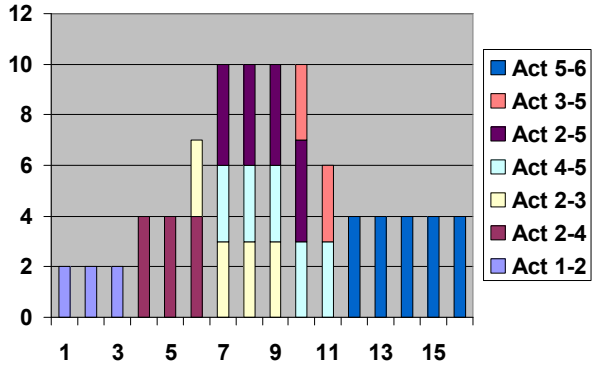
Steps in Resource leveling contd..

- The two resource loading charts obtained from steps 2 and 3 are compared.
- The two charts provide the two extreme arrangements of resource requirements.
- In the case that PEAKS AND VALLEYS are seen in the utilization pattern for a resource, the activities are manipulated by visual inspection and an acceptable resource requirement is found between the two extremes.
- The bottom-line is to ensure continuous deployment of resources and to avoid large variations in the utilization pattern.
- One such compromise solution is shown in Fig below (also refer Table below). This figure has been obtained by delaying activity 2-5 and 2- 3 by the number of the float days beyond its early start time and leaving the rest of activities intact as given in Table first table.
- It has resulted in reducing the peak requirement (from 11 to 10) besides bringing a gradual change in resource requirement.

Resource loading table showing daily requirement of workers
AFTER LEVELING

ACT.	t	Res.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1-2	3	2	2	2	2													
2-4	3	4				4	4	4										
2-3	4	3						3	3	3	3							
4-5	5	3							3	3	3	3	3					
2-5	4	4							4	4	4	4						
3-5	2	3										3	3					
5-6	5	4												4	4	4	4	4
		Total	2	2	2	4	4	7	10	10	10	10	6	4	4	4	4	4

Resource leveled chart



Discussion

- As can be understood from this example, it would be extremely difficult to employ this technique of visual examination for large problems.
- Also, for simple problem though the leveling exercise can be completed in one attempt, however for larger problems the resource leveling cannot be carried out in a single step, and is a largely iterative process.
- Computers can be employed to a good advantage for leveling of resources under time constrained situation.
- A number of heuristics have been developed for this purpose.

RESOURCE ALLOCATION

- Here availability of resources is a constraint.
- In other words, the resources have fixed limits.
- For illustrating resource allocation, we take the same problem (Project network of Fig above, that of the resource leveling) which was used for illustrating resource leveling.
- The difference here however is resource constraint. Let's take the maximum availability of resources be 8.

➔In case it is not possible to resolve the resource over-allocation on a particular day, some activities may have to be delayed.

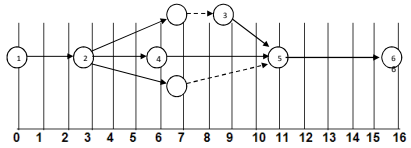
- The basic objective here is to find out which activities can be delayed and by how much and finally to arrive at the shortest possible time to complete the project satisfying the resource constraints.

RESOURCE ALLOCATION contd..

Basic assumptions/ Heuristic

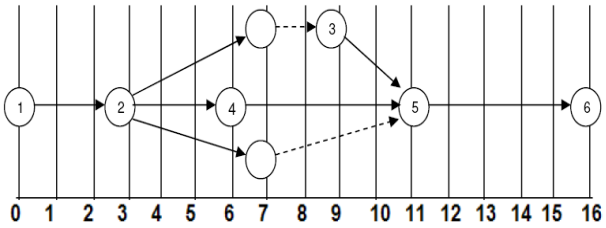
- When the resource requirement on a particular day exceeds 8 we decide the priority of competing activities on a predefined set of rules.
- Let the activities with earliest start time gets the first priority.
- In case, there is a tie between two or more activities, the priorities are decided on the basis of float available in the activities.
- That is the activity with the minimum float gets first priority.
- Further, non critical activities may need to be rescheduled in order to free the resources for critical activities. Also, let's not stop an activity in between once it has started.

The network of Fig 3.1 redrawn to the time scale



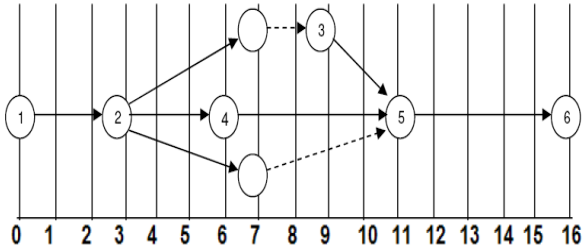
Day 1

Only activity 1-2 is scheduled for day 1 and only 2 resources are required which is less than the maximum.
Thus: on day 1, requirement – 2, availability – 8, remaining – 6.



Day 2 and 3

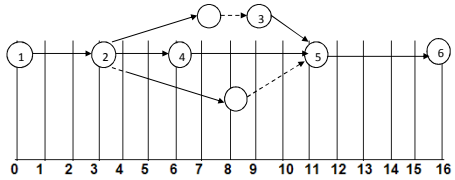
Activity 1-2 continues. Requirement – 2, availability – 8, remaining – 6.



Day 4

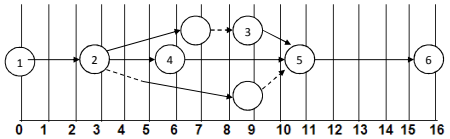
- The three activities 2-3, 2-4, and 2-5 can be started on day 4. Thus resource requirement would become 3 + 4 + 4 = 11, which is more than 8, the maximum limit. The decision rule 'activity with least float gets priority' for resource assignment comes into play here.
- Activity 2- 4 lies on the critical path i.e float =0 and hence resources need to be allocated to it first. The activity 2- 4 requires 4 unit of resources, availability is 8, thus resources remaining after assigning to 2-4 is 4 (8-4). Next in queue is activity 2-3 with float = 2 days. Thus resources are assigned to 2-3. The requirement of this activity is 3, while now the availability is 4, thus 1 resource is left out after this allocation.
- Activity 2-5 is left out since it needs 4 resources but the available resource is just 1, hence we need to postpone this activity. Also, the float of this activity is reduced to 3 now.

Day 4



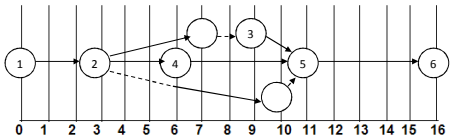
Day 5

Activity 2- 4. Requirement -4 Availability – 8 Remaining – 4
Activity 2- 3. Requirement -3 Availability – 4 Remaining – 1
Activity 2-5 again has to be postponed because of the unavailability of resources.
Also, the float of this activity is reduced to 2 now.



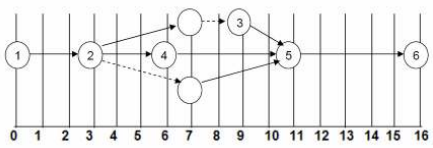
Day 6

Activity 2- 4 . Requirement -4 Available – 8 Remaining – 4
Activity 2- 3 . Requirement -3 Available – 4 Remaining – 1
Activity 2-5 again has to be postponed because of the unavailability of resources.
The float remaining for this activity is 1.

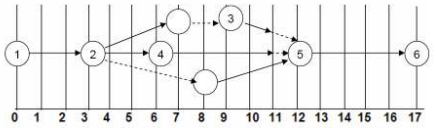


Day 7

Activity 2- 3 . Requirement -3 Availability – 8 Remaining – 5
Activity 4 -5 lies on the critical path and hence needs to be allocated resources.
Requirement – 5 Availability – 5 Remaining – 0
Activity 2-5 again has to be postponed because of the unavailability of resources.
The float left for this activity is now 0.



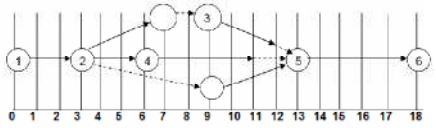
Day 8



Activity 4- 5 continues. Requirement -5, availability – 8, remaining – 3.
Activity 2-5 is now critical. The resources required are 4 but the availability is only 3.
Hence we need to postpone this activity by a day. This increases the duration of the project by 1 day.

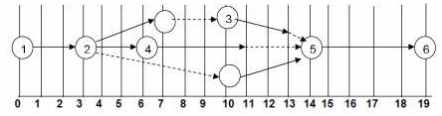
Day 9

Activity 4- 5 . Requirement -5 Available – 8 Remaining – 3
Activity 2 -5 . No resources are available. Hence we need to postpone this activity by a day again.
The total project duration now becomes 18 days



Day 10

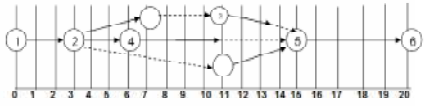
Since activities in progress can't be stopped in between,
hence resources must be allocated to them first.



Activity 4- 5 . Requirement -5 Available – 8 Remaining – 3
Activity 2 -5 . Not sufficient resources available. Hence we need to postpone this activity by a day again.
As per the given heuristic the activity 3-5 can't be scheduled now. Postpone activity 3-5.
The total project duration now becomes 19 days.

Day 11

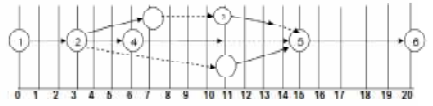
Since activities in progress can't be stopped in between,
hence resources must be allocated to them first.



Activity 4- 5 . Requirement -5 Available – 8 Remaining – 3
Activity 2 -5 . Not sufficient resources available. Hence we need to postpone this activity by a day again.
Again as per the given heuristic the activity 3-5 can't be scheduled now. Postpone activity 3-5.
The total project duration now becomes 20 days.

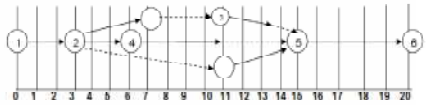
Day 12

Activity 2 -5 . Requirement – 4. Availability – 8. Remaining – 4
Activity 3 –5. Requirement – 3. Availability – 4. Remaining – 1



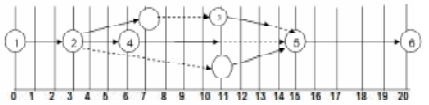
Day 13

Activity 2 – 5 continues. Requirement – 4. Availability – 8. Remaining – 4
Activity 3 –5 continues . Requirement – 3. Availability – 4. Remaining – 1



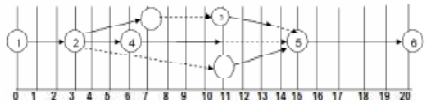
Day 14

Activity 2 – 5 continues. Requirement – 4. Availability – 8. Remaining – 4



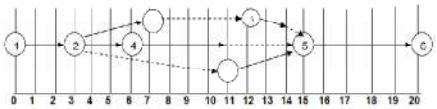
Day 15

Activity 2 – 5 continues. Requirement – 4. Availability – 8. Remaining – 4



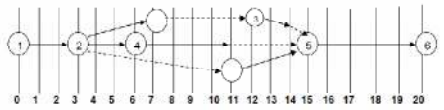
Day 16

Activity 5 – 6. Requirement – 5. Availability – 8. Remaining – 3.



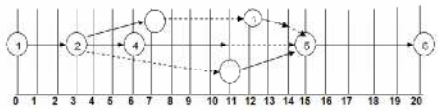
Day 17

Activity 5 – 6. Requirement – 5. Availability – 8. Balance – 3.



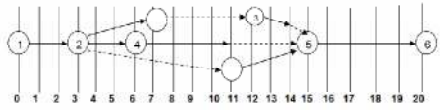
Day 18

Activity 5 – 6. Requirement – 5. Availability – 8. Remaining – 3.



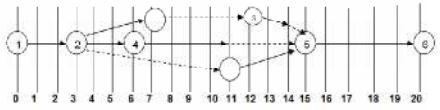
Day 19

Activity 5 – 6. Requirement – 5. Availability – 8. Remaining – 3.



Day 20

Activity 5 – 6. Requirement – 5. Availability – 8. Remaining – 3.



Discussion

- the project duration has been increased by 4 days from original 16 days with no resource constraint to 20 days with resource limit of 8.
- The resource requirement varies from ____to 8. The resource loading chart for the total project duration is shown in Fig_____.
- The steps illustrated above can be carried out manually only if the project is small. For large projects involving multiple resources we need to look to computer programs.
- The examples presented for resource leveling and resource allocation are that of very simplistic nature.
- First of all, we have considered only a single type of resource which is used for all types of activities.
- Further we have considered that the resource is interchangeable across different activities.
- Unfortunately in real life situations both these assumptions do not hold true. In practice we have to deal with different types of resources such as equipment, materials, and labours etc. and further a single activity may require more than one type of resources.

NETWORK CRASHING AND COST TIME TRADE OFF

- CPM is based on the assumption that duration of an activity can be reduced or crashed to a certain extent by increasing the resources assigned to it.
- As is known the execution of an activity involves both the direct costs and indirect costs.
- However, there is no point in attempting to crash all the activities by increasing the resources.

- Any reduction in duration of critical path activities can reduce the project duration.
- An activity can be performed;

➔at its normal or most efficient pace or

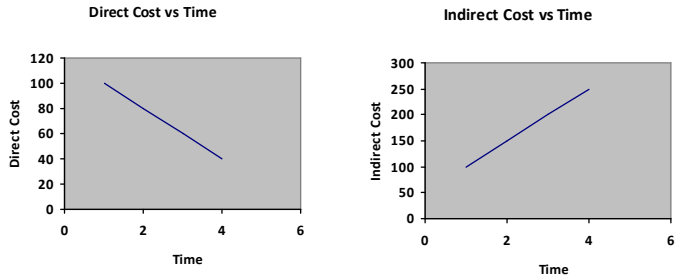
➔**'normal duration'**

➔ it can be performed at higher speed.

➔**'crash duration'**

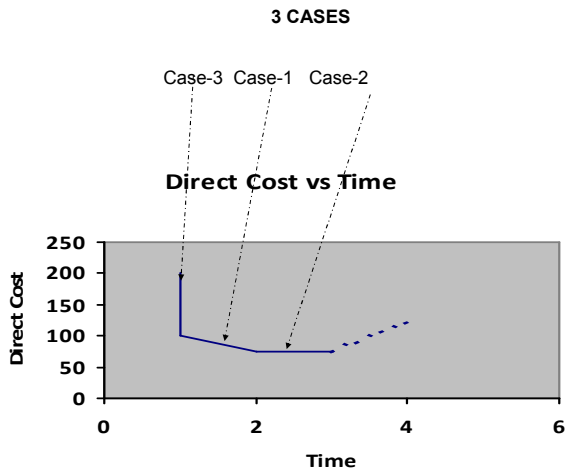
- Some activities along the critical path sometime need to be shortened in order to reduce the overall duration of the project.
- This leads to a decrease in the indirect expenses (due to decrease in duration) and an increase in the direct expenses (due to more mobilization of resources).
- The relationship between the cost of the job and the duration has been assumed to be linear. The steeper the slope of the line, the higher the cost of expediting the job at an earlier date.

Time cost trade off

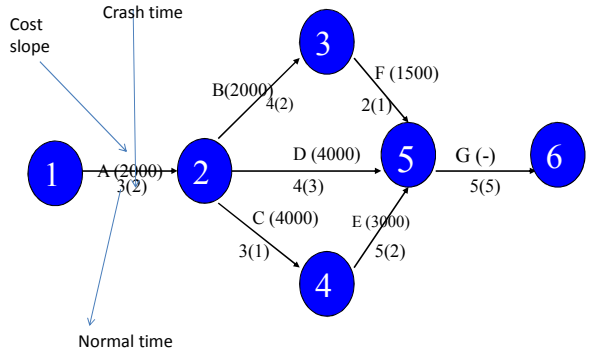


Crashing

- This expedition of activity at an earlier time is referred to as Crashing.
- There are 3 cases that normally arise –
  - Line sloping down to the right – The steeper the slope, the higher the cost of crashing.
  - Horizontal line – No cost of crashing.
  - Vertical line – The activity can't be shortened regardless of the extra resources applied to it.



EXAMPLE



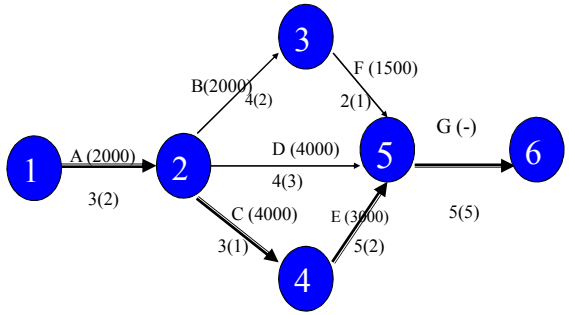
Details of activity cost and duration

Computation of slope for direct Expense!

Activity	Normal		Crash		Cost slope Br./ day
	Duration	Cost	Duration	Cost	
1-2 (A)	3	5000	2	7000	2000
2-3 (B)	4	6000	2	10000	2000
2-4 (C)	3	9000	1	17000	4000
2-5 (D)	4	5000	3	9000	4000
4-5 (E)	5	7000	2	16000	3000
3-5 (F)	2	8000	1	9500	1500
5-6 (G)	5	20000	5	20000	-

- The indirect expenses are Br. 6000 / day.

Network used for illustrating crashing



Critical path : A-C-E-G or 1-2-4-5-6
Project Duration-16 days

Important points

- The point of the minimum cost of project is known as the optimum point.
- In order to find the optimum point, the project network is drawn based on the normal duration of the activities. This is the maximum length schedule.
- The duration of the project is thus noted.

Important points

- It can be shortened by expediting jobs along the critical path. If the added cost of expediting the job is less than the saving in the indirect expenses which result from shortening the project, then a less expensive schedule can be found.
- New schedules are found as long as there is a reduction in the cost of the project.

Important points

- As can be observed from this small example, it is possible to crash some activities such as 1-2, 2-3, 2-4, 2-5, 4-5, and 3-5, while it may not be possible for some activities to be crashed such as 5-6 (both normal and crash duration are same here).

Solution

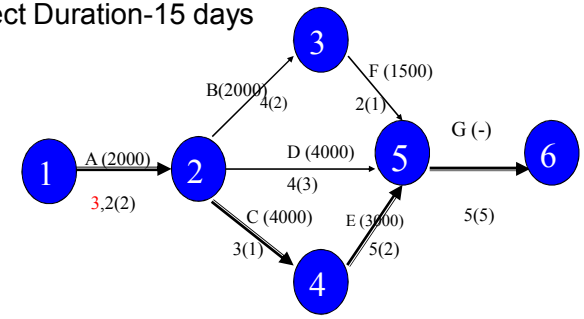
- The total project cost if all the activities are executed at their normal pace would be = normal costs of activities 1-2, 2-3, 2-4, 2-5, 4-5, 3-5, and 5-6 + (indirect cost per day x duration of project) = (5000 + 6000 + 9000 + 5000 + 7000 + 8000 + 20000) + **6000 x 16** = 60,000 + 96,000 = 156,000.

Solution contd..

- To shorten the project duration, we have to shorten the duration of activities along the critical path (1-2-4-5-6).
- We observe that the activity 1-2 is on the critical path and has the least slope (Br. 2000/day) and hence can be crashed first. This activity can be crashed by 1 day, thus the project duration reduces by a day. Project duration has become 15 days now.

Revised Network after crashing by 1 day

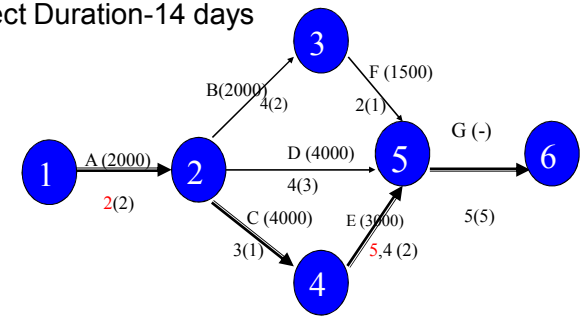
Critical path : A-C-E-G or 1-2-4-5-6
Project Duration-15 days



The project cost =
156,000 + 2000 – 6000 = 152,000.

Revised Network after crashing by additional 1 day

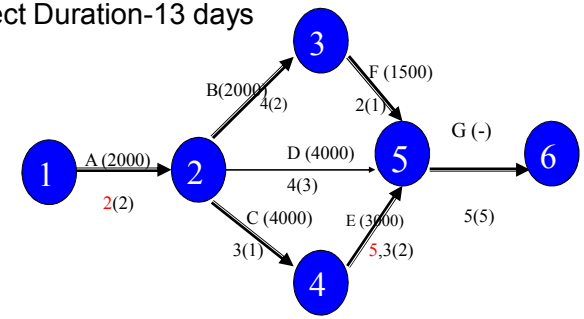
Critical path : A-C-E-G or 1-2-4-5-6
Project Duration-14 days



The project cost =
152,000 + 3000 – 6000 = 149,000. .

Revised Network after crashing by additional 1 day

Critical paths : A-C-E-G or 1-2-4-5-6 and 1-2-3-5-6
Project Duration-13 days



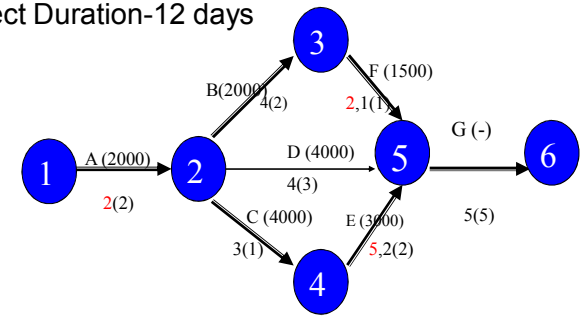
The project cost =
149,000 + 3000 – 6000 = 146,000. .

Crashing option now

Option	Cost (Rs /day)
C and B	4000 + 2000 = 6000
C and F	4000 + 3000= 7000
E and B	3000 + 2000= 5000
E and F	3000 + 1500=4500

Revised Network after crashing by additional 1 day

Critical paths : A-C-E-G or 1-2-4-5-6 and 1-2-3-5-6
Project Duration-12 days

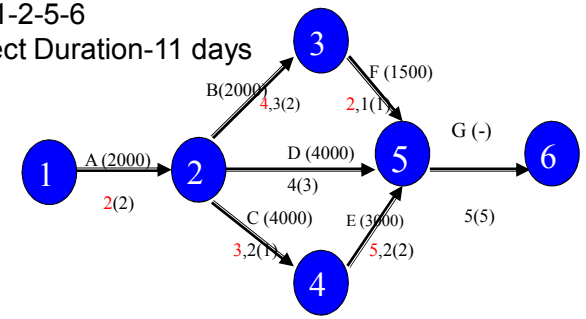


The project cost =
146,000 + 4500 – 6000 = 144,500. .

Revised Network after crashing by additional 1 day

Critical paths : A-C-E-G or 1-2-4-5-6 and 1-2-3-5-6 and 1-2-5-6

Project Duration-11 days



The project cost =
144,500 + 6000 – 6000 = 144,500.

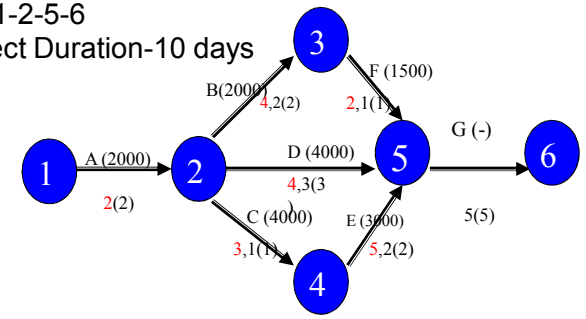
Option available now

- to crash activities B, C and D together by 1 day
- the cost of crashing the three activities together is equal to the sum of cost slopes of activities 2-3, 2-4, and 2-5 that is Br. 10,000.
- Thus project duration becomes 10 days.

Revised Network after crashing by additional 1 day

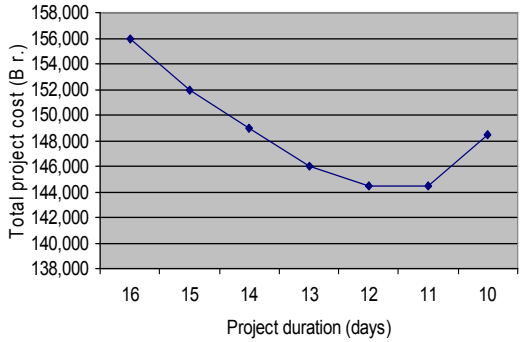
Critical paths : A-C-E-G or 1-2-4-5-6 and 1-2-3-5-6 and 1-2-5-6

Project Duration-10 days



The project cost =
144,500 + 10000 – 6000 = 148,500.

Time Vs cost for the example problem



LOB

- In LOB, the time is usually plotted on horizontal axis, and units or stages of an activity on the vertical axis.

➔The production rate of an activity is the slope of the production line and is expressed in terms of units per time.

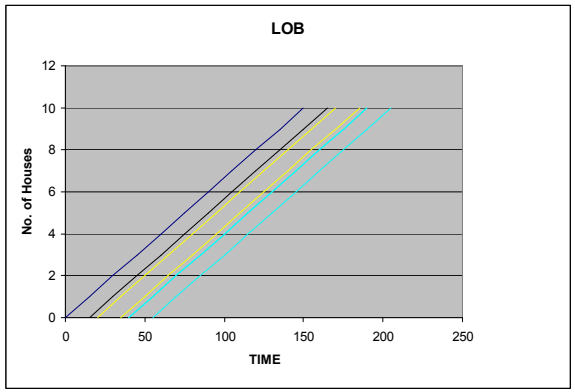
- The method uses *man-hour estimate* and the *optimum crew or gang size.* The LOB diagram can be plotted once the *man hour estimates* and *optimum size of crew* are determined by the planner based on his or her experience or in consultation with the implementing agencies such as vendor or subcontractor.

➔Two oblique and parallel lines, whose slope is equal to the actual rate of output will denote the start and finish times respectively of each activity in all the units from the first to last.

LOB

- This technique can be applied to construction projects for repetitive unit projects such as mass housing, high rise buildings, tunnels, etc.
- A typical LOB diagram is shown in the next slide for housing construction.

LOB diagram for scheduling of a housing project



Example

- Consider an example to illustrate the construction of LOB for scheduling of a housing project, where 10 houses are to be constructed.
- For simplicity let's assume that substructure, superstructure, and finishing are the only three activities involved in the construction of a house.
- Further, let's assume that substructure, superstructure, and finishing take 10, 20, and 15 days respectively for a single house.
- To provide for the margin of error in the time taken to complete each of these operations, the time buffer is usually placed in between the two activities.
- Let's assume the buffers in this case to be of 5 days. Thus the construction of a single house needs 55 days to complete (10 + 5 + 20 + 5 + 15 = 55).

Example contd..

- That is the first house is completed in all respect on 55th day from start. It is further assumed that now onwards every 5th day one house is to be completed i.e. second house on 60th day from start, third house on 65th day and so on and the last house or 10th house gets completed on 100th day.
- This is called the rate of construction, thus rate of construction here is one house every 5 days. This rate is represented diagrammatically, for all the three activities where completion dates is drawn for each of the 10 houses. Thus, the substructure, superstructure and finishes of all houses are joined by sloping lines. These form a series of bands which are the LOB schedules, for each activity.
- It can be seen that in this case, all the sloping lines are parallel to the handover line. Each activity is proceeding at the rate of 1 house per week at the same rate as the handover schedule.

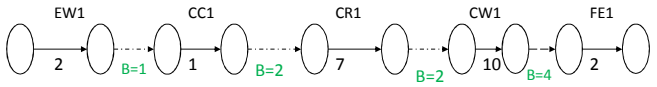
Buffer

- In practice, each time buffer would probably be different.
- The construction manager selects the buffer according to his own experience and his own forecast of the risk or difficulties in delays that may occur.
- For example, if in a particular locality, carpenters are known to be in short supply, longer buffers would be inserted after activities involving carpenters.
- Conversely, only very small buffers may be required when little difficulty is expected in reaching, planned gang, size and output.
- The crew size is determined in such a way that production rate of all the activities become more or less uniform.
- The buffer can be uniform or non uniform depending on the situation. In practice, each time buffer would probably be different. For example, if in a particular locality, welders are known to be in short supply, longer buffers would be inserted after activities involving welders. Conversely, small buffers would be sufficient when not much difficulty is foreseen in mobilizing the required crew size

Drawing LOB

- Step 1: **Construction of network logic diagram for one segment**
- **As a first step, usually a logic or network diagram for one of the many units to be produced is prepared and incorporated into the LOB schedule.**
- **The logic diagram for one segment of retaining wall is as given below.**

- **The notations and durations of activities are assumed to be the same as for the previous illustrations.**



- The estimation of duration is dependent on the quantity of each of the activities and the associated crew.
- The quantities involved and the number of workers assumed is shown for all the activities associated with the construction of retaining wall in the following table.
- It is assumed that there will be work for 12 hours each day. It is also assumed that the formwork, reinforcement and concreting would be done by the same set of workers.

Activity	Quantity for one segment	Productivity assumed	Man Hours per activity	No. of workers assumed	Theoretical duration (days)	Duration (t) days taken for LOB schedule
Earthwork	100 cum	3 MH / cum	300	13	1.92	2
PCC	8 cum	20 MH/cum	160	13	1.03	1
Concrete Raft	70 sqm formwork	4 MH/sqm	880	11	6.67	7
	2 MT reinforcement	60 MH/MT				
	24 cum concrete	20 MH/cum				
Concrete wall	500 sqm Formwork	4 MH/sqm	3515	30	9.76	10
	4.4MT reinforcement	60 MH/MT				
	62.5 cum concrete	20 MH/cum				
Fencing	100 RM	1.5 MH/RM	150	7	1.79	2

Step 2: Buffer estimation and 'start' and 'end' buffer identification

- The buffers are estimated in such a manner that crew of one activity does not interfere with the crew of other activity.
- The buffers B for this illustration have been estimated and shown under the dotted arrows.
- For example B=1 means a buffer of one day between the earthwork and plain cement concrete activities.
- It would be pertinent here to distinguish between a start and end buffer.
- In case the rate of construction (speed) of subsequent activity is faster than the activity under consideration buffer is kept at the end. A→bBb→C(fast)slaw
- Conversely if the rate of production of subsequent activity is slower than the activity under consideration then the buffer is placed at the start.
- For example, completion of earthwork is achieved in 2 days while the completion of plain cement concrete is achieved in 1 day itself. Naturally the speed of the later activity is faster than the former. Thus in order to avoid the interference of the later crews with the crews of earthwork activity, it is desired to have the end buffer and derive the start of plain cement concrete as shown in Table below.
- Now considering the case of plain cement concrete and concrete raft it is clear that the speed in the later is slow (concrete raft is taking 7 days to complete) thus requiring a start buffer.

Step 3 Computations of start and finish of first and last segment of each of the activities involved

- Using the concept of start and end buffer the start and finish of first segment and the fifth segment are computed for each of the activities involved with the construction of retaining wall.

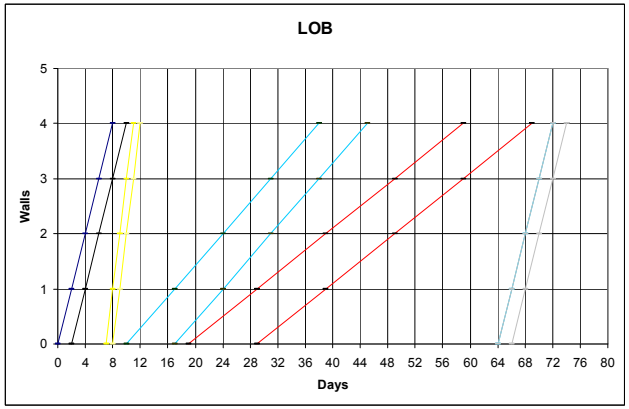
Computations of line of balance schedule for the construction of retaining wall

Activity	Duration (t) days	Time (T) (n-1) walls	Buffer Days	Type of buffer	Start day of wall 1	Start day of wall 5
Earthwork	2	8	1	End	0	0 + 8 = 8
PCC	1	4	2	Start	11– 4=7	0+2+8+1= 11
Concrete Raft	7	28	2	Start	7+1+2= 10	10+28=38
Concrete wall	10	40	3	End	10+7+2=19	19+40=59
Fencing	2	8			59+10+3-8=64	64+8=72

Step 4 Drawing line of balance chart

- The resulting start and finish time for each activity for all the segments are shown in the following manner.

Fig____ LOB Schedule for construction of retaining wall



Step 5 Adjusting the schedule

- It can be noted from Fig _____that the rate of construction of different activities are not uniform.
- In other words, these are not 'balanced' thus some improvement is desirable.
- In order to bring about a more 'balanced' schedule a number of steps can be taken.
- For example, the crew size can be adjusted since we can neither make changes in the quantity nor in the assumed productivity.
- From the above figure it can be seen that we can reduce the speed of plain cement concrete activity by reducing the number of crew.
- Also, we can try to increase the speed of the activities 'concrete raft' and 'concrete wall'. This can be achieved by increasing the speed of construction of these activities by increasing the number of crews.

- The ideal situation would be to aim for 'parallel scheduling' as shown in Fig___for housing construction example wherein the rate of construction of each of the activities is same.
- In our retaining wall example, it is also possible to achieve a parallel scheduling by decreasing the speed of plain cement concrete activity and increasing the speed of concrete raft and concrete wall activities to 2 days per segment, and thereby reducing the overall duration for the construction.
- However, such reduction in duration should be checked for its technological feasibility as well as its cost saving potential.
- For example if it is found that the extra cost incurred in increasing the crew size and thereby reducing the overall duration has more cost associated with it than the saving it generates by decrease in indirect cost, there is no point in such reduction in duration.

- Thus there could be many possible schedules and the choice of a particular schedule will be dependent on the decision maker and the situation prevailing at that time.
- Needless to say the computations for start and finish times of some of the activities may undergo change.
- The revised computations for start and finish times after adjusting the crew size is shown in Table___.
- The overall completion time is now 29 days as against 74 days. Please also note that the buffer between the activities concrete wall and fencing has now been changed to 4 days from previous buffer of 3 days.
- The revised LOB schedule based on these computations for our retaining wall example is shown in Fig__. As explained earlier, there could be further improvements possible.

RESOURCE PLANNING

- Planning construction Manpower
- Planning construction materials
- Planning construction equipments
- Planning construction costs

Focus

1. Manpower requirement planning
2. Materials requirement planning and ABC analysis of materials

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Planning construction Manpower

- Scope of construction Planning Manpower
  - Establishing Workers' Productivity standard
  - Scheduling construction site workers
  - Project manpower grouping
  - Designing workers
  - Financial incentive scheme

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Introduction

➔The project construction manpower planning is primarily concerned with estimating the workers' productivity, scheduling manpower employment, and structuring it into workers' teams and work grou[ps] with a view to economically match[ing] manpower supply with the task requirem[ents]

Main objective

Matching manpower supply with the task requirements economically

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Project planning team: typical manpower planning functions

1. *Determining expected labor productivity*
2. *Estimating workers requirements for each work package*
3. *Scheduling data-wise, category-wise, project direct labor*
4. *Establishing construction teams*
5. *Organizing task forces*
6. *Allocating labor during execution stage*
7. *Monitoring workers productivity at site*
8. *Recording productivity data*
9. *Costing and controlling manpower cost*
10. *controlling manpower mobilization, distribution and demobilization.*
11. *Defined job requirements for key executive and staff appointments.*
12. *Assist in recruitment of personnel*
13. *Assist in controlling manpower costs.*
14. *Assist in controlling manpower costs*
15. *Assist in training and induction of manpower.*

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A. Establishing workers' productivity standard

➢ The challenging task

a. Workers required *=(Work quantity x Workers' productivity standard) / Completion period*

b. Workers' productivity standard *=worker output norms X production efficiency factor*

Where

i. workers' productivity standard is defined as the effort in man-days or man-hours needed for accomplishing a unit quantity of work, while working efficiently but allowing for normal delays and wastage.

ii. Work quantity of the activity involved is expressed in standard work units

iii. Completion period is taken as working days or hours planned or earmarked to accomplish the task.

iv. Workers' production norms are expressed in man-days or man-hours, category-wise, required for accomplishing the unit work.

v. Production efficiency factor is the multiplier used to convert production norms into productivity standards expected under job conditions at the site.

✓ Quantity can be accurately estimated from the dwg & spec . If the work is to be completed within the stipulated period, the variable in assessment of the worker's requirement is the productivity standard.

➢ Identifying requisite skills

➔Construction involves multi-skill technology for its wide range of related activities.

➔These skills varies with the nature of job, type of project …

➔The first step towards determining productivity standard is to identify the trade workers needed for execution of the project.

➢ Worker's production planning Norms

The workers production planning norms (or planning data) indicate the extent of effort required in terms of man-hours (MH) to accomplish a unit quantity of specified work or activity.

Example

➔Consider a task involving 160 m2 of fixing timber formwork for the roof slab of a single story building. The time earmarked for completion is four days, working eight hours per day. If workers' team consisting of two skilled workers and an unskilled worker can install the formwork at the rate of 1.25m2/hr,

Effort Required=(Formwork quantity)/(Output per team)
=160m2/(1.25 m2 per team-hours)
=128 team-hour

Teams required=Team-hours/(Completion period)
=128/(4*8)
=4

This is the number of crews!

Workers required=4(2 skilled +1 unskilled)
=8 skilled + 4 unskilled

- Experienced estimators and planners compile the workers' production planning norms for estimating the manpower requirements. In the absence of such planning data, appropriate norms can be evolved using one or a combination of the following methods:

(a) Analyzing the past performance data
(b) Abstracting data from published norms
(c) Work-studying the actual work process

1. Analyzing past performance data (Statistical analysis techniques for evaluating workers production norms)

The long standing construction firms compile their basic production norms by analyzing the past performance data of similar works, using statically techniques.

➔Drawbacks of the methods

i. No two projects are exactly alike, and therefore the past performance data of various projects have to be carefully examined for their suitability while determining the norms for a given projects
ii. The construction production output is constantly improving over time because of induction of better techniques and latest equipment. The statistical analysis of past performance therefore my not conform to the state-of-the-art/ high-tech.
iii. Analysis of the past data is useful only if the data available is reliable. The degree or reliability of such data needs to the ascertained prior to analysis.
iv. Statistical analysis must not blindly compound the inefficiencies or problems of the past. The actual context in which the past performance data was recorded should be studied, and the data of inefficient or problematic working periods should be discarded prior to processing.

2. Selecting published production norms

✓ A planner can derive production norms for a project by relating them with the published production norms of professional institutions or that prepared by the concerned government bodies.
✓ The workers productivity norms vary from area to area. Workers coming from different areas, even when employed on a similar job, have different productivity. This difference is due to a blend of many ethnic and environmental factors➔ this resulted in the introduction of different relative productivity index for different location.

3. Work studying construction process

➔work-study, using the method study and time study techniques, aims at finding the optimum method of production with specified resources and the time required to perform the production tasks, so as to establish production norms of workers and production capacity of machine.

➔Method study- aims to find an optimum method of executing of work by minimizing all waste.

- ➔Purpose of the study is defined
- ➔The method of execution is recorded
- ➔The sequence of work and resources employed are critically examined, and
- ➔Areas of inefficiency are identified with the aim of reducing wastage

➔various studies of construction industries show that a workman devotes only 40-60% of his time in the actual execution of the work, with the rest spent on wasteful and unproductive activities like waiting, traveling, and personal breaks.

➔Example

➔Consider a project with a production cost of $100million, having 20,000man-months as direct labor, of which 60% is non-productive time. If 15% of the wastage resulting from non-productive time is eliminated by using improved methods then the resulting saving in labor cost would be:

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➔Labor costed=20% of the project cost(estimated while tendering)

=0.2*100 million

=20million

➔non-productive labor is 60% of labor cost, 0.6*20=12million

➔Saving in cost by reduction of 15% of non-productive time=0.15*12million =$1.8million

➔Saving as percentage of productive work value=($1.8million /(40% of 20 million))*100=22.5%

➔After the method study has es
omplishin
ed b
performance.

Work study in manufacturing industry

Work study in Construction industry

Because each construction projects has unique tasks which are affected by situations!!!!!!!!!!!!

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➢ Factor Affecting production Efficiency

✓ The computation of production efficiency factors depends upon numerous variable which affect workers' productivity in actual job conditions at the project site. These variables vary from project to project, and over place and time. Some of the typical factors affecting the workers' production efficiency are;

i. Work complexity
ii. Repetition of work
iii. Quality control –stringent quality control is sensitive projects, like in the construction of a nuclear reactor, calls for frequent inspections, which involve elaborate documentation and is a time consuming task. They increase the non-productive time of workers and, in turn, reduces productivity by 10-25%.
iv. Equipment intensive tasks – less susceptible to productivity changes than the labor-intensive ones
v. Supervision – an effective and efficient supervisor can get a higher productivity from workers
vi. Climate and weather change
vii. Labor availability

➔Role of management

- The project management has a key role to play in planning and controlling productivity.
- It is responsible of specifying the weekly target of work to be accomplished by the workers as well as how the works are to be executed and using which resources .
- During the execution stage, the management provides the necessary resource support and closely monitors the performance. Each week, it compares the planned target with the work accomplished, evaluates variances, analysis causes of variances, takes corrective measures.
- It provides feedback to the workers on their past performance, and communicates performance improvement measures. It suitably rewards the workers who have done exceptionally well, and keeps the morale of the work force high. The productivity is bound to suffer if the management fails to fulfils its role and obligations effectively.

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➔Determining production efficiency factor

- There is no single or exact method to determine production efficiency factor as there are too many factors involved, and, it is neither feasible nor desirable to evaluate the effect of all such factors affecting production efficiency. At the planning stage, a project planner or estimator cannot take care of all the controllable and enforceable factors. It is possible that some of these may have been considered while establishing the basic productivity norms.
- Example for typical project:

Production elements	Efficiency (%)
Nature of work	75
*Supervision (Competence of the supervisor)	90
Labor market	80
Climate and working condition	60
Equipment orientation	50
total	355

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Production elements	Efficiency (%)
Nature of work	75
Supervision	90
Labor market	80
Climate and working condition	60
Equipment orientation	50
total	355

➔the average production efficiency(355/5)is 71.0% of the basic productivity norms.

➔this is evaluated average production efficiency factor

➔ The standard productivity for each item of work is then obtained by multiplying the basic norms with the evaluated average production efficiency factor of the work process.

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B. scheduling Site Workers

➔ **Direct and indirect workers**

➔ need of categorizing is for ease of estimating, planning, accounting and controlling!

➔ **Direct Manpower-** these are the construction site workers who can be identified with execution of the client's permanent works such as those listed in the bill of quantity. The direct manpower constitutes 75-90% of the total manpower employed at the project site.

➔ The direct construction workers include foremen and tradesmen, skilled in various engineering trades, in addition to the semi skilled and unskilled manpower. The trades men include carpenters, bar benders, masons, plumbers, electricians, painters and decorators…

➔ Generally the wages of construction site workers are accounted on a daily or hourly basis, and their activity-wise requirement is computed using the workers' productivity standards!

Name of the project Contract No.

Contract value Duration

Contractual Date of completion

Sl No.	Description (Labor category)	Total Man-months	Month1	Month2	Month3	….	Month6	Remarks
1	Unskilled							
2	Semi skilled							
3	Skilled							

➔format for direct manpower scheduling!

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➔**Indirect manpower-** the indirect manpower covers all supervisors, staff and workers other than those in the direct manpower. It is required to support the direct manpower, both technically and administratively. It generally consists of the project management and administration group.

➔The indirect manpower is generally accounted on monthly basis!

- Depending on the invoicing to be done per month a month-wise schedule for project staff is maintained.

Name of the project Contract No.

Contract value Duration

Contractual Date of completion

Sl No.	Staff category	Nos. required	Requirement		Remarks
			From	To	
1	Project Manager	1	M1	M10	
2	Resident Engineer	1	M1	M10	
3	Civil Engineer	1	M2	M10	
4	Jr Engineer -Electrical	1	M6	M10	
5	Jr. Engineer- Civil	1	M2	M7	
6	Jr. Engineer- Civil	1	M6	M7	For roadworks
7	Foreman	1	M2	M7	For formwork activities
8	Foreman	1	M2	M7	For concreting activities
9	Accountant	1			For plumbing and sanitary works
10	Time Keeper	1			

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➔The workers' scheduling methodology involves

1. Scheduling direct construction site workers
2. Adding indirect construction site workers

1. Scheduling direct workers

➔The direct manpower schedule indicates, data-wise as well as category-wise, the worker strength required to accomplish the scheduled work.

➔The past performance data is invaluable for conceptualizing manpower forecasts!

➔The bar chart of construction work schedule with its date of commencement and completion of each activity of work-item forms the basis for developing the direct workers schedule. Since activity has a specified duration, work content, and manpower required for its accomplishment, the daily average manpower required for each scheduled activity can be assessed as:

=(quantity of work X labor productivity standard in man-days)/ duration in days

C. Project manpower grouping

NATURE OF GROUPS

➔The project manpower organization depicts the hierarchy of organizational groups of people.

➔The number of organizational groups depend upon the magnitude and complexity of a project-a simple project may have only a few while a large, complex one may have many.

➔The project manpower groups can be broadly divided into the following function units.

(a) Command and Control groups: to manage the project and to provide necessary logistic support,

(b) Construction task forces: to execute the construction works

(c) Resource/ Support centers: to provide men, materials, and machinery support to the construction task force

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FORECASTING INDIRECT MANPOWER

➔ Indirect manpower requirement is related to the management functions. In construction projects, these functions can broadly be grouped as;

- ➔Project office management
- ➔Design and drawing management
- ➔Estimation and contracts management
- ➔Planning and monitoring management
- ➔Project administration and personnel management
- ➔Cost and finance management
- ➔Materials management
- ➔Plant and equipment management
- ➔Quality management
- ➔Construction supervision management
- ➔Supporting service management

➔The extent of indirect manpower needed to perform the project functions depends upon the type and size of the project.

Sl.No	Departments	Manager		Senior Engineer		Junior Engineer	
		No.	Period	No.	Period	No.	Period
1	Office management						
2	Planning Management						
3	Technical management						
4	Contract Management						
5	Personnel management						
6							
7							

Structuring Site Organization

➔The structuring of work groups into construction task forces and direct support service centers is accomplished by applying the three classic principles of designing formal organizations:

(a) Unity of Command : no man can serve two bosses simultaneously that is a person should receive orders from and responsible to only one superior.

(b) Scalar Principle : chain of command or hierarchy showing the superior – subordinate relationship.

(c) Span of Control: puts a limit to the number subordinates reporting to a superior.

➔ The project management team aims at achieving objectives economically. It employs motivational tools to increase production and productivity. The art of motivating lies in creating environment, developing systems, and directing efforts in such away that they meet the organizational goals as well as the needs of those participating in the process, with everyone working enthusiastically as one team under the relationship of the project manager.

➔ The motivational approach, can be divided into behavioral approach and financial incentive schemes. In a construction project;

➔ The behavioral motivational approach→ create healthy working environment

➔ Financial incentive scheme → benefits the participants by;

(a) Increase production and productivity, without any appreciable increase in estimated cost

(b) It helps workers in increasing their earnings and gaining job satisfaction without affecting the estimated cost of the project.

→The financial incentive scheme may vary with the type of the project, nature of the task and employment teams of workers.

(a) Time related schemes → overtime work will be paid in proportion to the basic hourly wages

(b) Job-related schemes→ according to the measurable job completed

(c) Lump-sum work payment → time saved from standard time fixed for completing the job, lump-sum amount paid for completing the fixed quantity of a specified job.

(d) Profit sharing bonus → these can be paid as bonus after a predetermined time, say, quarterly, half-yearly or yearly.

Planning construction materials

→ Construction materials cover all types of materials used in construction including electrical and mechanical fittings fixture, devices and instruments that are incorporated during the construction of permanent works and temporary supporting works at site.

→ Efficient materials management in project environments calls for an integrated approach covering numerous functions such as materials planning, purchasing, inventory control, store-keeping and warehousing, handling and transportation, codification and standardization, and the disposal of the surplus.

→ * **Materials planning**, which is the key function of materials management, is closely linked with project planning and control set-up.

→ aim to develop a plan for procurement and stocking of construction materials so as to provide at the site materials of the right quality in right quantity at the right prices from the right sources at the right time.

❑Construction materials planning involves :-

- *identifying materials,*
- *estimating quantities,*
- *defining specifications,*
- *forecasting requirements*
- *Locating sources for procurement*
- *Getting samples of materials approved*
- *Designing materials inventory*
- *Developing procurement plans and*
- *Monitoring flow of materials till the connected construction works are completed.*

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ABC Classification of construction Materials

→The primary concept/purpose of classifying materials is to control quality, cost and timely supply. There are many factors that need consideration while classifying materials. These include storage space, shelf life, supply reliability, inventory costs, ease of identification, construction sequence, transportation requirement, price, procurement time, procurement source and project life. Some of the general categories are;

(a) bulky, one –time purchase, repetitive use, and minor materials

(b) Vital, essential and desirable materials

(c) Indigenous and imported materials

(d) High price, medium price and low price materials

(e) High usage value, medium usage value and low-usage value materials

→The most commonly used method for classifying construction materials is to group them into high-value, medium-value and low-value materials. *→ this classification is achieved using the ABC analysis. The prerequisite for applying the ABC analysis technique is that the project should have a standardized bill of materials listing the physical quantities (including standard usage), unit rate and total cost for each item.

BILL OF MATERIALS					
S.No.	Item of materials	Unit	Quantity	Rate	Amount

→The materials management technique of ABC analysis is based on the principle of "control by selection" which implies that is not necessary to give the same degree of attention to procurement , storage, issue and control of all types of materials.

Group Class	Total Items	Inventory Costs
A	10%	70%
B	20%	20%
C	70%	10%

Methodology (Please Refer page 246(CHITKARA))

(a) Identifying materials required and estimate quantity of each material.

(b) Obtaining the approximate unit rate for each item.

(c) Assessing the requirement during the period under consideration, i.e. yearly or project completion basis.

(d) Determine the usage value of each type by multiplying the quantity required with the corresponding unit rates.

(e) Calculate the percentage usage value of each materials with respect to total project or yearly usage cost. Write this percentage against each item in the appropriate column.

(f) Arrange the items in the descending order of usage value.

(g) Consider materials in the descending order of usage value. Compute commutative usage value against each item.

(h) Draw two horizontal lines demarcating the descending order of the cumulative purchase values at 70% level and 20% level.

(i) The three groups separated by the two horizontal lines starting in descending order of usage value can be classified as 'A' group, 'B' group and 'C' group.

Materials Usage Standard

→Some wastage is inevitable in actual work. This wastage in materials is generally expressed as a percentages of materials calculated theoretically from the quantities of the work involved, and are termed as 'standard wastage'. The total quantity of materials to be provisioned should cater for the standard wastage by increasing the theoretical quantity, proportionally.

➔ Materials to be provisioned;

=Theoretical quantity of materials X [{100+standard Wastage(%)}/100]

➔ It may be noted that standard wastage caters for wastage during utilization only for causes considered beyond control at the site. In addition to the controllable wastage, there is wastage which falls in the category of controllable wastage. The main cause of controllable wastage are;

(a) Wastage on account of designers specifying non-standard materials having unattainable specifications.

(b) Wastage due to incorrect purchasing resulting in over buying, wrong buying, unnecessary buying and untimely buying.

(c) Wastage in transpiration and handling including breakage and pilferage.

(d) Wastage during storage resulting from deterioration, improper storage, breakage, obsolescence.

➔since, controllable wastage falls under the purview of the materials management staff the additional provisions to compensate for such wastage should be made by them so as to ensure that the right quantity of materials are available at the right time.

Planning materials Inventory

➔A balanced inventory act as a cushion between supply and site requirement till supplies are received. This include predetermined safety stock to cater for slippages in delivery schedules. It is therefore, necessary to hold a planned stock of construction materials at the project site to ensure a timely supply of the expected quantity of materials at the appropriate time for smooth execution of planned construction activities with least investment on inventory.

Costs of inventory

The effective management of inventory involves a tradeoff between having too little and also too much inventory.
Inventory costs:

i. Ordering Costs: **requisitioning, preparation of purchase order, expediting, transport and receiving and placing in storage, set-up costs**

ii. Carrying Costs: **interest on capital locked up in inventory, storage and handling costs, insurance, depreciation, and property taxes.**

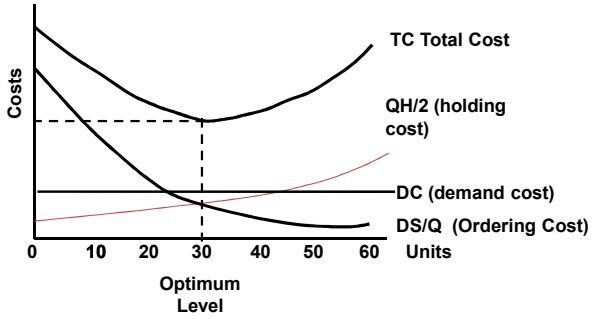
iii. Shortage Costs: **arise when inventories are short of requirement for meeting the needs of production or the demand of customers.**

- **Loss of sales, loss of customer goodwill, disruption of production schedules.**

Inventory Management – Minimizing Costs

- The goal of effective inventory management is to minimize the total costs that are associated with ordering and holding inventories.
- Choose the level of inventory with the lowest total cost after estimating the different expenses with varying inventory levels.

Inventory Management – Minimizing Costs (Cont'd)



The two basic questions relating to inventory mgt

- **Size of the Order:** Q optimal
- **The Level to Order:** Q level

i) Order Quantity
Economic Order Quantity (EOQ)

- **The Economic Order Quantity refers to the order size that will result in the lowest total of order and carrying costs for an item of inventory.**
  - Order costs increase as number of orders increase
  - Carrying costs increase as large stocks are kept

Variables in the EOQ model:

D: The forecast usage/demand for goods or raw materials for a year is known,
Q: Quantity Ordered,
S : Cost per Order,
H: Holding cost
C : Price per Unit (other than carrying and ordering costs)
TC: Total Costs of ordering and carrying

i) Order Quantity
Economic Order Quantity (EOQ)

By adding the item holding and ordering costs together we can determine the total cost curve, which is used to find the O_{opt} inventory order point that minimizes total costs. Using calculus we take the first derivative of the total cost function with respect to Q, and set the derivative (slope) equal to zero., solving for the optimized (cost minimized) value of $O_{opt.}$

$$TC = DC + \frac{D}{Q}(S) + \frac{Q}{2}(H)$$

$$\frac{dTC}{dQ} = 0 + \frac{-DS}{Q^2} + \frac{H}{2} = 0 \qquad Q^2 = \frac{2DS}{H} \qquad Q = \sqrt{\frac{2DS}{H}}$$

i) Order Quantity
Economic Order Quantity (EOQ)

D=Annual demand
S=Order cost
H=Annual holding cost

Example: Given the following for a company:
D= Annual Demand= 20,000 Units
S= Cost to place an order= Birr 2,000
H=Holding cost=Birr1200

$$Q = \sqrt{\frac{2DS}{H}} \qquad Q = \sqrt{\frac{2x2{,}000\ x20{,}000}{1200}} = 258\ .2 units$$

ii) Order Level
Economic Order Quantity (EOQ)

We also need a reorder point to tell us as what inventory level we need to place an order. If the usage rate of materials and lead time for procurement are known with certainty then;

The ordering level = Lead time in days for procurement X Average daily usage

$$R = L \times \bar{d}$$

L=Lead time, Average daily usage= $\bar{d}$

Question

- The annual demand a construction ABC for a certain material for construction is 15,000 units per year (250 working days per year); it costs Birr 50 t0 place an order , birr 20 per unit annual holding cost , an order lead time of 5 days and birr 120 per unit to buy the material.

I. What is the optimal size of your order?
II. What your reorder point is?
III. What is your total annual cost?

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Project construction equipment

- Construction equipment planning aims at identifying the construction equipment for executing project tasks, assessing equipment performance capability ,forecasting the date wise requirement of numbers and type of equipment, and finally participating in the selection of equipment to be acquired.
- Equipment purchase involves initial heavy investments. In the long run, equipment adds to profitability by reducing the overall costs,

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- Provided the equipment is properly planned, technically scrutinized, economically procured and effectively managed. Poor selection and bad managing of equipment are generally attributed to task mismatched, unplanned requirement forecast, hasty purchase decisions, inadequate repairs and spares supply , and lack of preventive maintains.

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Selecting construction equipment

- Task considerations
- Equipment owning and operating costs
- Mechanical characteristics
- Equipment acquision options

1.Task considerations

- The task objectives of production tasks in terms of nature of the task and the quantity of work to be accomplished economically, within specified time, and under a given site conditions.

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PLANNING OF CONSTRUCTION EQUIPMENT

- Extent of mechanization
- Nature & Magnitude of work
- Indigenous equipment
- Cost comparison for Machine & Labour
- Large quantity of material handling & speed of construction
- Possibility of using manual labour should be explored

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CRITERIA FOR SELECTION OF EQUIPMENT

- Use of available equipment
  - New Equip may not be fully utilized
  - Utilization on future projects unforeseen
  - Economics, Depreciation etc
- Suitability of Job Conditions
  - Demand of job. Soil & Valley Condition, climate, working condition etc

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- Uniformity in types
  - Min No of Types
  - Common types of engines for different machines
- Size of Equipment
- Use of Standard Equipment
  - Commonly manufactured
  - Easily available
  - Moderately priced
  - Spare parts should be easily available

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- Unit Cost of Production
  - Freight
  - Packing
  - Insurance
  - Erection
- Country of Origin
  - Soft currency
- Availability of Spare parts

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- Versatility
- Selection of Manufacturer
- Suitability of local labour
- Adaptability for future use

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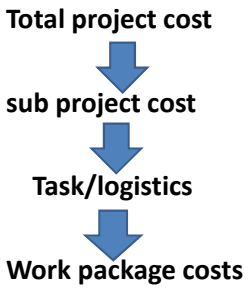
Project cost control

- Project cost control aims to control changes to the project budget.
- it provides management with cost related information for making decisions with a view to complete the project with specified quality, on time and within the budgeted costs.

Cost control preliminaries

- **Cost estimates**: the feasibility study during the inception stage outlines the approximate cost of the project.
- Master control estimate is prepared during project planning stage.
- **Cost planning:** cost break down generally follows the hierarchy pattern of work break down structure.

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- **Budgeting costs :**budget relates the costs with time progress.
- **Measurement of cost performance:** The EVA technique is an important tool in evaluating and forecasting.
- Earned Value analysis is a method of performance measurement.
- Earned Value is a program management technique that uses "work in progress" to indicate what will happen to work in the future.

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- **Three quantities** form the basis for cost performance measurement using Earned Value Management are:
  - ✓ **Budgeted Cost of Work Scheduled (BCWS) or Planned Value (PV),**
  - ✓**Budgeted Cost of Work Performed (BCWP) or Earned Value (EV) and**
  - ✓ **Actual Cost of Work Performed (ACWP) or Actual Cost (AC) .**

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- Budgeted Cost of Work Scheduled (BCWS) or Planned Value (PV) – The sum of budgets for all work packages scheduled to be accomplished within a given time period.
- Budgeted Cost of Work Performed (BCWP) or Earned Value (EV) – The sum of budgets for the work that has actually been completed to date.
- Actual Cost of Work Performed (ACWP) or Actual Cost (AC) – The actual cost incurred in accomplishing the work performed within a given time period. For equitable comparison, ACWP is only recorded for the work performed to date against tasks for which a BCWP is also reported.

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Additional terms are defined to record cost and schedule performance and program budget:

Performance Measurement Baseline (PMB) – The sum of all work packages Budgeted Cost of Work Scheduled (BCWS) for each time period, calculated for the total program duration. The PMB forms the time-phased budget plan against which project performance is measured.
Budget At Completion (BAC) – The sum of all the budgets allocated to a program.

Schedule Variance (SV) – The difference between the work actually performed (BCWP) and the work scheduled (BCWS).

Cost Variance (CV) – The difference between the planned cost of work performed (BCWP) and actual cost incurred for the work (ACWP).

Cost Performance Index (CPI) – The ratio of cost of work performed (BCWP) to actual cost (ACWP). CPI of 1.0 implies that the actual cost matches to the estimated cost. CPI greater than 1.0 indicates work is accomplished for less cost than what was planned or budgeted. CPI less than 1.0 indicates the project is facing cost overrun.

Schedule Performance Index (SPI) – The ratio of work accomplished (BCWP) versus work planned (BCWS), for a specific time period. SPI indicates the rate at which the project is progressing.

Estimate At Completion (EAC) – It is a forecast of most likely total project costs based on project performance and risk quantification. At the start of the project BAC and EAC will be equal. EAC will vary from BAC only when actual costs (ACWP) vary from the planned costs (BCWP).

Estimate At Completion (EAC)-
Most common forecasting techniques are some variations of:

1.EAC = Actual to date plus a new estimate for all remaining work. This approach is most often used when past performance shows that the original estimating assumptions were fundamentally flawed, or they are no longer relevant to a change in conditions.

2.EAC = Actual to date plus remaining budget. This approach is most often used when current variances are seen as atypical and the project management team expectations are that similar variances will not occur in the future.

3.EAC = Actual to date plus the remaining budget modified by a performance factor, often the cumulative cost performance index (CPI). This approach is most often used when current variances are seen as typical of future variances.

4.EAC = Budget At Completion (BAC) modified by a performance factor, cumulative cost performance index (CPI). This approach is most often used when variances from BAC have occurred.

Estimate To Complete (ETC) – The difference between Estimate At Completion (EAC) and the Actual Cost (AC). This is the estimated additional cost to complete the project from any given time.

Variance At Completion (VAC) – The difference between Budget At Completion and Estimate At Completion (EAC). This is the dollar value by which the project will be over or under budget.

Earned Value Management Terms:

Term	Description	Interpretation
PV (BCWS)	Planned Value	What is the estimated value of the work planned to be done?
EV (BCWP)	Earned Value	What is the estimated value of the work actually accomplished?
AC (ACWP)	Actual Cost	What is the actual cost incurred?
BAC	Budget at Completion	How much did you BUDGET for the TOTAL JOB?
EAC	Estimate at Completion	What do we currently expect the TOTAL project to cost?
ETC	Estimate to Complete	From this point on, how much MORE do we expect it to cost to finish the job?
VAC	Variance at Completion	How much over or under budget do we expect to be?

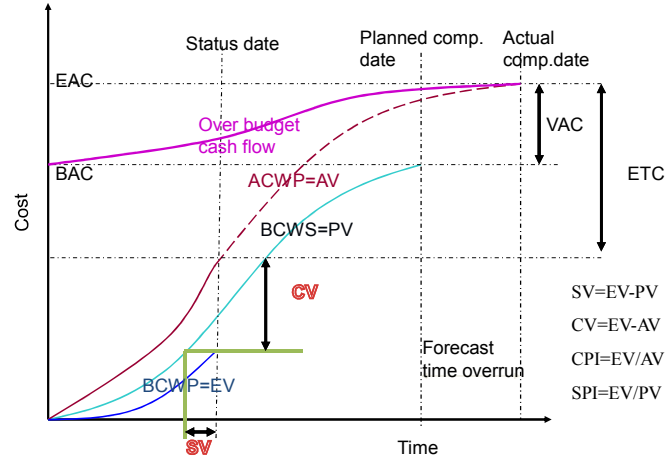
Earned Value Management Formula and Interpretation:

Name	Formula	Interpretation
Cost Variance (CV)	EV – AC	NEGATIVE is over budget, POSITIVE is under budget
Schedule Variance (SV)	EV – PV	NEGATIVE is behind schedule, POSITIVE is ahead of schedule
Cost Performance Index (CPI)	EV / AC	I am [only] getting ____ cents out of every $1.
Schedule Performance Index (SPI)	EV / PV	I am [only] progressing at ___% of the rate originally planned.
Estimate At Completion (EAC) Note: There are many ways to calculate EAC.	BAC / CPI AC + ETC	As of now how much do we expect the total project to cost. $____ • Used if no variances from the BAC have occurred • Actual plus a new estimate for remaining work. Use: when original estimate was fundamentally flawed

COST CONTROL(EVA)

	AC + BAC – EV AC + (BAC – EV) / CPI	• Actual to date plus remaining budget. Used when current variances are atypical. • Actual to date plus remaining budget modified by performance. When current variances are typical.
Estimate To Complete (ETC)	EAC – AC	How much more will the project cost?
Variance At Completion (VAC)	BAC – EAC	How much over budget will we be at the end of the project?

Project cost control: the EVA



Project cost control: the EVA

Benefits of EVMS

1. It is a single management control system that provides reliable data.
2. It integrates work, schedule and cost using a work breakdown structure (WBS).
3. The associated database of completed projects is useful for comparative analysis.
4. The cumulative cost performance index (CPI) provides an early warning signal.
5. The schedule performance index (SPI) provides an early warning signal.
6. The CPI is a predictor for the final cost of the project.
7. It uses an index-based method to forecast the final cost of the project.
8. The periodic (e.g. weekly or monthly) CPI is a benchmark.

Project time control

- Construction projects are time bound and all project activities are directed toward the achievement of project time objectives.
- Project time control aims at the timely exception of work according to the project planned schedule and applies corrective measures in case of time deviations.
- In its boarder sense , time control implies the control of the entire planning system as time is directly or indirectly related with all activities and project functions.

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Time progress monitoring methodology

- The baseline for time monitoring is project master construction schedule (PMCS).
- It is generally drawn in the bar chart format.
- Time monitoring of complex projects can broadly be divided into the following three stages:

a. measuring the progress of current activities

b. Updating subproject plans

c. Updating the project master schedule

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Measuring the progress of current activities

- At any point of time, activities can be classified into completed activities, in progress activities, and still to start activities .
- The state of activities is measured by comparing their actual progress against the monthly or quarterly bar chart work program.

Updating sub- project plane

- A project is be said to be proceeding smoothly as long as the activities are being performed as per schedule.

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- But at times, deviations from the schedule do occur. Some of the reasons for the delay could be inaccurate estimation of the duration of completed activities, unforeseen climate condition, non supply of materials on time, effect of changes in scope of work, inadequate employment of resources and labor strikes.

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Time reduction techniques

- The two commonly used techniques for reduction techniques for reducing time over runs are:
- Compressing the critical path
- Time- cost trade off
- **Time Compressing the critical path**: Time compression is the process of reduction of the project completion time with out any appreciable change in the cost of activities.
- It involves splitting (where feasible) of the critical activities into smaller activities, either by using different methods of execution with out any appreciable change in resources or changing to lower levels of activity details.

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- Some of these smaller activities may form a chain of activities and others may be parallel. Generally , it is paralleled component of critical activity that compresses the project completion time.

Time-cost trade off technique (discussed the previous lectures)

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Example on EVA technique

Given project

- ✓ 5km road project
- ✓ 5month contract time of completion
- ✓ Budgeted cost of Br. 500M

Scheduled(time and cost)

- ✓ 1km➔1month➔100M.Br

Physical progress

- ✓ At the end of 2nd month➔ 1.5 km
- ✓ Actual cost➔ 180M.Br

Question

- ✓ Under spending?/ over spending?
- ✓ Behind schedule?/ ahead schedule?

Example on EVA technique

Solution

Cost over run=180-150= 30M

- ✓ BCWS=200M➔ here the schedule is measured by Br.
- ✓ BCWP=150M
- ✓ ACWP=180M(Earned Value)➔ from cost statement of the project(Report)

Variance

- ✓ SV=BCWP-BCWS=-50M

(schedule variance in terms of money, it could be in MH or equipment, labor..)

- ✓ CV=BCWP-ACWP=-30M(negative variance as of monitoring day)

Example on EVA technique/cost controlling

Conclusion

As the SV & CV indicates the project is Overspending and as well lagging behind the schedule.

SPI=BCWP/BCWS=150/200=0.75➔ behind schedule

CPI=BCWP/ACWP=150/180=0.83➔ cost overrun

Example on EVA technique/cost controlling

Budget at completion ➔BAC=500M

Estimate at completion

Estimate to completion
3.5km each with 100

- ✓ EAC= ACWP+ETC=180+350=520M
- ✓ EAC=(ACWP/BCWP)x BAC=(180/150)x500=600

(EAC=BAC/CPI=500/0.83=600)

- ✓ EAC=AC+BAC-EV=180+500-150=530
- ✓ EAC=AC+ (BAC-EV)/CPI=180+(500-150)/0.83=601.69
- ✓ Which one is the exact estimate????

Variance at competition

VAC=BAC-EAC=500-???=???

End of the Course!

A.Y 2013