

Chapter Three: Construction Scheduling Fundamentals

Construction scheduling is a mechanical process for setting in sequential order various operations in a construction project by the dates of starting and completing each operation of the work in such a manner so that the whole work should be done in an orderly and systematic way. During fixing of start and finish time of each operation suitable margin should be given for unexpected delays due to bad weather, lack of proper labor, etc.

- The schedule should also indicate quantity of work involved, material, labor equipment, money required and allotted time to each operation and the process of work.
- The accuracy or validity of schedule depends on the validity of the work quantity and productivity of estimates used.

Principal use of schedule for different phases:

a. Before Starting

- Provides an estimate of time required for each portion of the project as well as for the total project.
- Establishes the planned rate of progress
- Forms the basis for managers to issue instructions to subordinates
- Establishes the planned sequence for the use of manpower, materials, machines and money.

b. During Construction

- Enable the manager to prepare check list of key dates, activities, resources, and soon.
- Provides a means of evaluating the effect of changes and delays
- Serves as the basis for evaluating progress
- Aids for coordination of resources.

c. After completion of construction

- Permits a review and analysis of the project as actually carried out
- Provide historical data for improving future planning and estimating.

Planning and scheduling is indispensable for construction work of any type.

- ✧ Alternative methods of construction can be examined at the planning stage so that a most economical method can be identified and chosen
- ✧ As the time of start and finish of each activity is known, so we can make adequate arrangement of resources.
- ✧ Scheduling also indicate the quantity of work and duration so we can arrange plant and equipment without idealness.
- ✧ The total time of completion of the project can be known
- ✧ With the help of actual progress charts it is known whether the work is lagging behind or not.
- ✧ Knowing the inter-relation of various activities and relative importance of each activity at any stage of construction will help in fixing their priorities properly.
- ✧ The Ultimate advantage of scheduling is the execution of construction work in efficient manner without wastage of inputs. This will result in gaining maximum possible construction economy.

3.1 Creating the Schedule

Scheduling can be classified or created as follows:

- Construction schedule
- Material Schedule
- Labour Schedule
- Equipment schedule
- Financial Schedule

1. Construction Schedule

Construction schedule may be defined as a roaster prepared for the execution of different operations in the construction of a certain project. In this schedule the work is subdivided into many sub-head or operations. The amount of work, rate of completing the work making allowance for bad weather and other unforeseen circumstances, number of men required (both skilled and unskilled) number and type of equipment needed and interrelationship of various operations is calculated, the sequence of various

operations is given the date of completion of each operation is mentioned. Construction schedule governs the other schedule.

2. Material Schedule

Moving and storing of material in any form is known as material schedule. It is a schedule which shows the dates of delivery of each type of material at site.

The materials should be delivered at the project site before it is needed. An excessive and early delivery is not desirable.

Item No	Descripti on of material	Unit	Total quanti ty	Month of year				
				October				November
				Week				
				1	2	3	4	
1	Cement	bags		100	150	150	200	

Material delivery schedule format

3. Labour Schedule

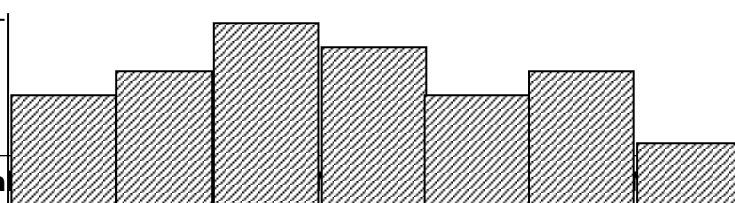
Labour schedule is a graphical representation of the labour requirement of a certain days or during certain weeks. Labour schedule will indicate the nature and quantity of labour required for the execution of different operations on different dates. The graph at bottom gives the true ides about the fluctuation of labour during the project. The engineer should arrange the labour in such away so that there are minimum labour fluctuations.

Item No	Activitie s	Weeks							
		1	2	3	4	5	6	7	8
1	Excavatio n	15	10						
2	Foundatio n		10	10	6				
3	Walls			15	15	15	10		
4	Roof Slabs						8		
5	Plastering							8	
	Total	15	20	25	21	15	18	8	

Bar chart

Labour

25
20
15
10



Labour Schedule graph

4. Equipment Schedule:

Equipment schedule shows the types and quantities of equipment required on particular dates in the entire project.

Item No	Type of Equipment	Months of the year on which equipment required						
		2005						
		Sep.	Oct.	Nov.	Dec	Jan.	Feb.	
1	Bulldozer	1	1	1				
2	Grader			1	1	1	1	
3	Dump trucks	3	3	4	3	3	3	

Equipment Schedule Format

5. Financial Schedule

Financial schedule shows the flow of money into a project. A construction schedule may be used to estimate the amount of funds that a contractor must provide in financing a project during construction.

Weeks after starting	Activities under construction	Expenditure per week	Cumulative expenditures
1	Excavation	\$6000	\$6000
2	Lean concrete, Rebar, formwork & concrete	\$10,000	\$16,000

Financial Schedule Format

3.2 Network Scheduling and PDM, PERT, CPM

An analysis of the construction schedule will indicate the approximate expenditures and receipts through any desired dates. The excess of expenditures over receipts indicates the amount of financing which the contractor must provide from sources other than the owner.

The following important rules apply to the estimation of activity durations:

- i) Evaluate activities one at a time, independently of all others. For a given activity, assume that materials, labor, equipment and other needs will be available when required,
- ii) For each activity assume a normal level of manpower and/or equipment. Compute the estimate duration by applying a crew or equipment production rate to the total number of units of work to be done. It is highly advisable to use the optimum resource needed for the execution of the activity.

Example: Activity duration to pour 230 m² of slab formwork, assuming a production rate of 1.5 m²/hr /crew can be established as follows

Duration = quantity/productivity= 230 m²/ 12 m²/day = 17.5 days

- If time units of working days are being used, assume a normal working day.
- Do not consider overtime or multiple shifts unless this is a usual procedure or a part of the standard work day.
- Be advised that productivity may increase with a learning curve

A variety of planning techniques are available of which only three are to be outlined indicating the advantages and disadvantages and the most application in practice.

❖ *The Networking Schedule Technique*

- ✚ *The Critical Path Method (CPM),*
- ✚ *The Precedence Diagramming Method (PDM)*
- ✚ *The Performance Evaluation & Review Technique (PERT)*

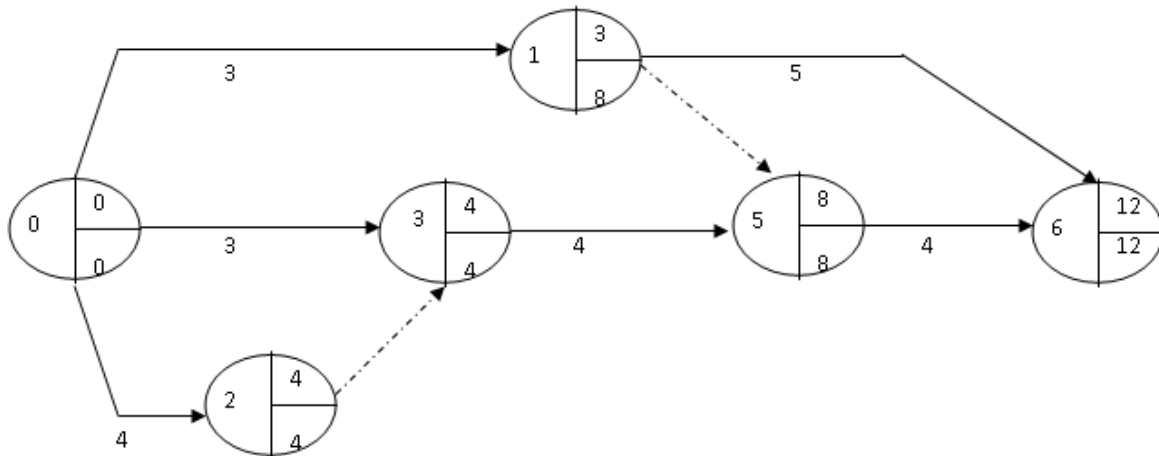
❖ *The Bar Charts*

1. The Networking Schedule Technique

✚ *The Critical Path Method (CPM)*

The most widely used scheduling technique is the critical path method (CPM) for scheduling, often referred to as *critical path scheduling*. This method

calculates the minimum completion time for a project along with the possible start and finish times for the project activities. Indeed, many texts and managers regard critical path scheduling as the only usable and practical scheduling procedure. Computer programs and algorithms for critical path scheduling are widely available and can efficiently handle projects with thousands of activities.



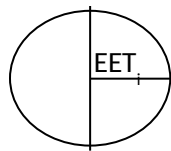
The Basis of CPM

The basic elements of a network analysis are activity and event.

An **event** is a point in time. It usually represents completion of a preceding activity and beginning of succeeding one. An event has no duration.

Event timing and associated terms

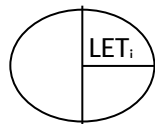
Earliest Event Time (EET) is the earliest time that an event can take place.



The EET of the first event, which usually is the start of the project itself, is taken zero while the EET of the subsequent event is calculated by adding the activity duration to it. If there are more than one activities leading to an event, the EET of that event will be the highest value obtained by adding activity durations to the EETs of the preceding events. Such process of determining EET by adding activity durations onto EETs of previous events is

known as *forward pass*, adopted from the process of moving forward from preceding to subsequent events.

Latest Event Time (LET) is the latest time that an event can occur without affecting the on time completion of the project. According to this definition, and unless otherwise specified so, the LET of the end event, such as completion of project, is taken to be equal to its EET. Thus the LETs of the remaining events are calculated by moving in a reverse path, hence termed backward pass, and subtracting the activity duration from the LET of the event the activity leads to. If more than one activity diverges from an event, then its LET would be the lowest value obtained by subtracting the duration of each activity from the LET of the respective succeeding events.



A *milestone* is a key event time when some decisive events happen. Example could be project completion day, meeting, delivery of specific critical output, phase transition etc.

Numbering of events: Numbering of a network serves to simplify the identification of an activity and computer programming. Though there are no strict rules in numbering events, for the sake of simplicity and reducing errors, it is useful to follow the following guidelines:

- ✓ Each activity should have a distinct and unique i-j numbers;
- ✓ As much as possible, the number of the preceding event (i) should be less than that of the succeeding one(j)
- ✓ At is advisable to leave some numbers to cater for possible inclusion of an event (or an activity) after finishing initial scheduling. Otherwise, renumbering could be cumbersome. However, in the event that no number was left during initial scheduling and is needed to insert a new event, it is possible to leave out the advice to number events in an increasing order and insert the event with a higher number.

Procedures in numbering:

- i. Number the start of the network as zero;
- i. Start with the top chain and number subsequent events serially till more than one activity emerges from an event or where the tail of an activity leading to it is not numbered;
- ii. Where more than one activity emerges out of an event, number the events in the top most chain serially till an event is reached where the tail event of an activity converging to that event is not numbered;
- iii. Where the tail event of the converging activity is not numbered, proceed with the next activity from the top chain.
- iv. Leave out some numbers to cater for possible inclusion of activities later on, or use 'even' or 'odd' event numbering.

An activity, as defined earlier, is an operation or process that consumes time for its completion, exception to this definition are dummy activities

Dummy activities are activities which have zero duration and consume no resource. They are introduced into a network diagram for a logical purpose. As will be discussed below, dummy activities will be present only on *activity on arrow network diagrams* to make sure that each and every activity is given a unique activity numbering, A_{ij}

Hammock or a summary of activity is bundle of activities used to gather a number of sub-activities into one master activity.

Activity timing and associated terms:

Earliest Start Time (EST) is the earliest time an activity can start assuming that all activities leading to this specific activity have taken place as early as possible.

$$EST_{ij} = EET_i$$

Earliest Finish Time (EFT) is the earliest time that an activity can be completed.

$$EFT_{ij} = EST_{ij} + d_{ij}$$

Latest Start Time (LST) is the latest time an activity can start without pushing the overall project beyond its stipulated completion time.

$$LST_{ij} = LET_j - d_{ij}$$

Latest Finish Time (LFT) is the latest time that an activity must be completed to ensure on time project completion.

$$LFT_{ij} = LET_j$$

Total Float (TF) is the maximum period of time that the earliest start of an activity can be floated without leading into overall project delay. Total float is the difference between LST and EST of a given activity.

$$TF_{ij} = LST_{ij} - EST_{ij} = LET_j - EET_i - d_{ij}$$

Free Float (FF) is the maximum period of time that the earliest start time of a given activity can be delayed without affecting the earliest start time of the subsequent activity.

$$FF_{ij} = EST_{jk} - d_{ij} - EST_{ij} = EET_j - d_{ij} - EET_i$$

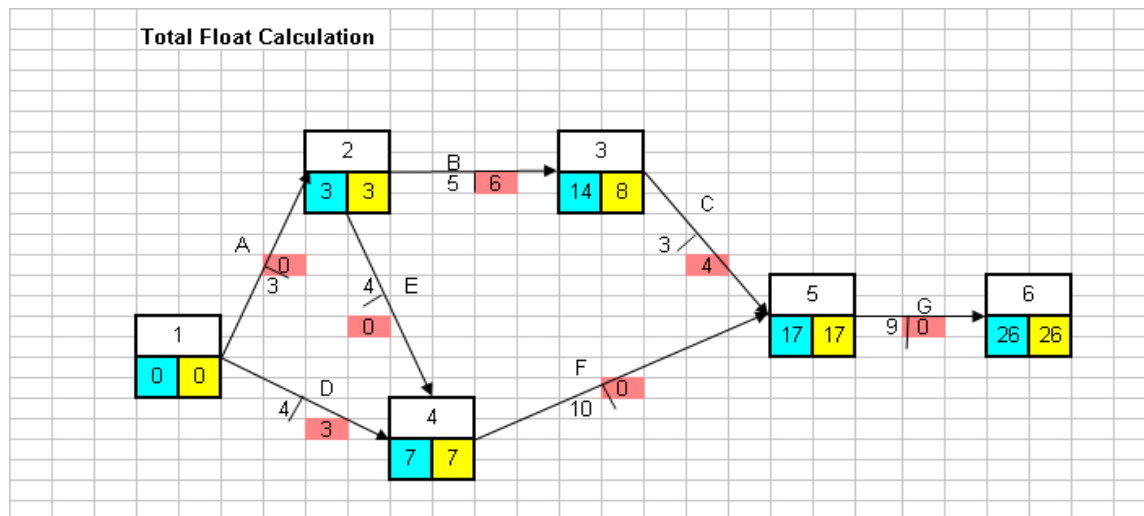
Critical activities are activities in the network diagram which have zero total float.

For example:

For activity B, float = $14 - (3+5) = 6$

For activity F, float = $17 - (7+10) = 0$

The calculated floats are shown in red.

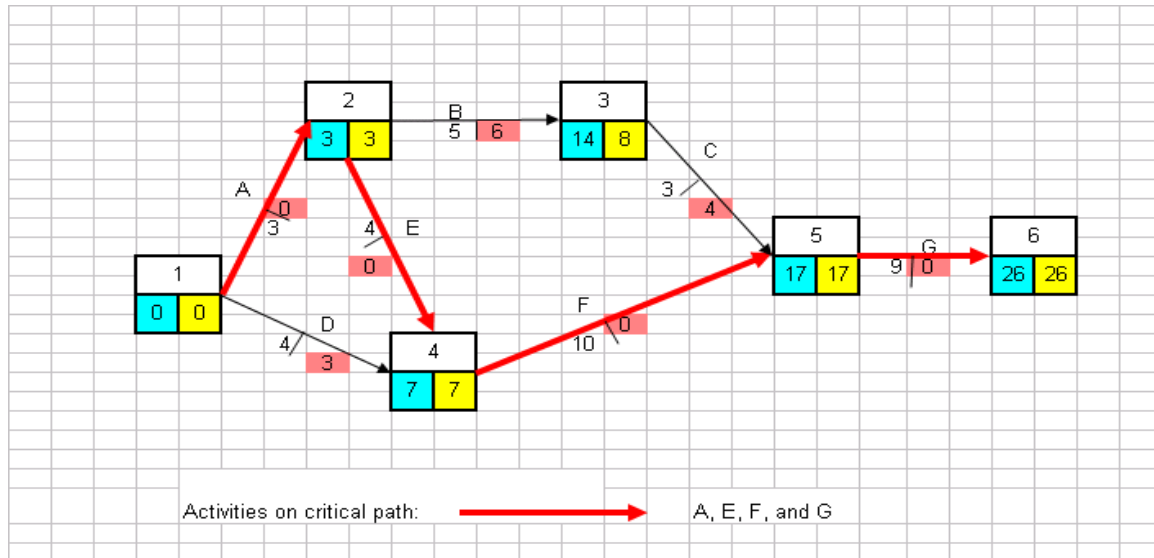


All activities having zero float are critical, and when connected, they form the critical path. The critical path is shown in red in the diagram.

Any delay in a critical activity prolongs the project duration.

Note:

- Critical path is the longest path through a network.
- It is the shortest time in which the project can be completed.
- Activities on critical path have zero float.
- There can be more than one critical path.



The *critical path* itself represents the set or sequence of predecessor/successor activities which will take the longest time to complete. The duration of the critical path is the sum of the activities' durations along the path. Thus, the critical path can be defined as the longest possible path through the "network" of project activities. The duration of the critical path represents the minimum time required to complete a project. Any delays along the critical path would imply that additional time would be required to complete the project. Formally, critical path scheduling assumes that a project has been divided into activities of fixed duration and well defined predecessor relationships. A predecessor relationship implies that one activity must come before another in the schedule. No resource constraints other than those implied by precedence relationships are recognized in the simplest form of critical path scheduling.

Si No	Act ivity	Dura tion	Event timings			Activity timings				Floats		Sensitivi ty ranking
			EET _i	EET _j	LET _j	EST _{ij}	EFT _{ij}	LST _{ij}	LFT _{ij}	TF	FF	
1	0-1	3	0	3	7	0	3	4	7	4	0	
2	0-3	3	0	4	4	0	3	1	4	3	1	
3	0-2	4	0	4	4	0	4	0	4	0	0	

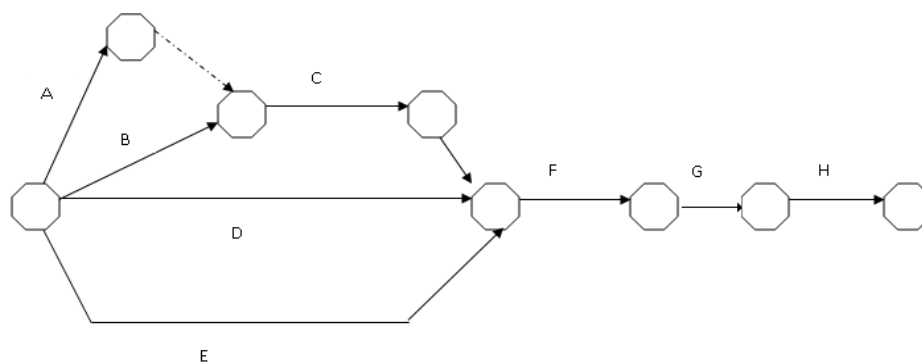
4	2-3	0	4	4	4	4	4	4	4	0	0	
5	1-5	0	3	8	8	3	3	8	8	5	5	
5	3-5	4	4	8	8	4	8	4	8	4	0	
6	1-6	5	3	12	12	3	8	7	12	4	4	
7	5-6	4	8	12	12	8	12	8	12	0	0	

Forms of network diagram

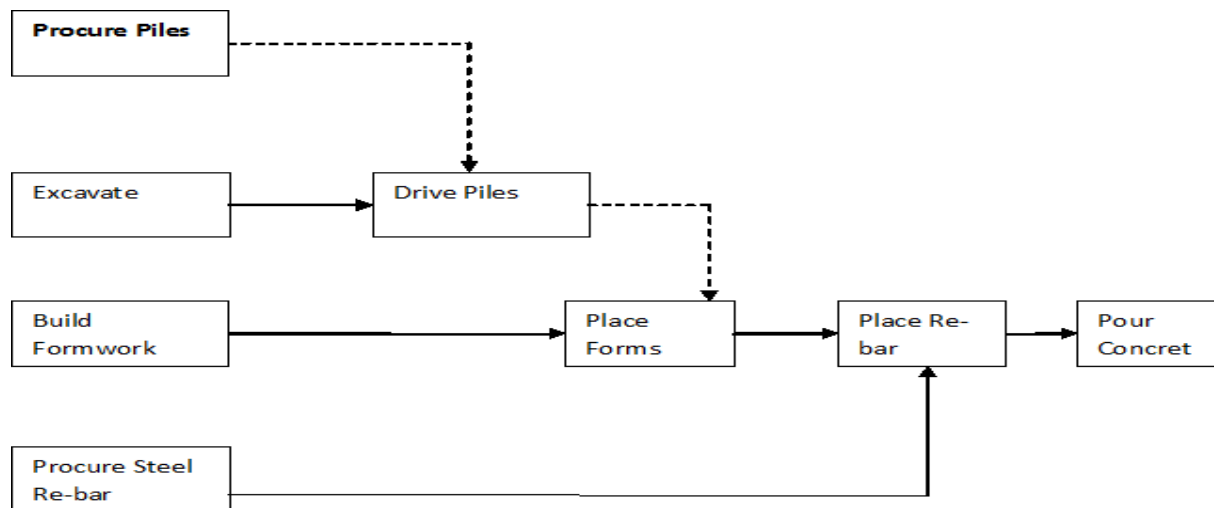
Network scheduling can take two forms: Activity on arrow notation or activity on node notation.

Example: Network schedule for pile foundation

Notation	Activity	Duration (days)
A	Procurement of Piles	5
B	Excavation	3
C	Drive Piles	4
D	Build Formworks (pile cap)	3
E	Procure steel re-bars	2
F	Place formworks (Pile cap)	1
G	Place Re-bars	2
H	Pour Concrete	1



Activity on arrow notation (AOA)



Activity on node notation (AON)

Important features of a network diagram:

- The arrow notation in the first diagram or the rectangular nodes in the second denote activities.
- The arrow notation in second diagram shows the precedence existing among the activities,
- The circular nodes in the first diagram designate activity events. All arrows must start and finish at this nodes. An event might describe as that instant of time when the latest finishing activity coming into that node has just been completed.
- Critical path is a path in the network, when the duration is summed up, provides the project completion time. Any lag on the starting or finishing time of these activities will be directly reflected as delay on the project completion period.
- Dummy activities are normally indicated with hidden arrow in a network and are not an indication of an activity but a logical connection between activities.
- Floating time is the time in which the starting and finishing time of an activity can be shifted without affecting the completion period of the project. Activities along the critical path have no floating time.

- Usually in AON diagram a 'Lag time' is used to show a period of time between finish of a preceding activity and start of its successor. Eg. A 7 day lag time for curing concrete

The Precedence Diagramming Method (PDM)

The network scheduling system in the CPM using the above AOA or AON methods assumes a strict sequential relationship upon which the start of an activity is predicated upon the completion of its immediate predecessors. This strict "start" only when the predecessors are finished relationship is called Finish to Start (FS). The limitation of the FS network representation is that it precludes those kinds of tasks that can be started when their predecessors are only partially completed.

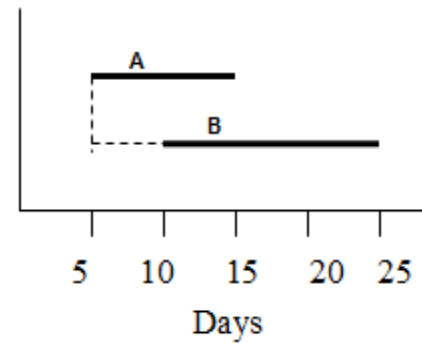
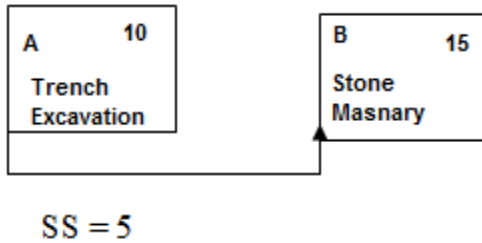
For example, when a building foundation is being constructed, "stone masonry work" activity can start as soon as some of the trench excavation has been accomplished. Although it might be necessary to have completed "trench excavation" before starting "stone masonry works", the point is that "stone masonry work" can begin before its immediate predecessor "trench excavation" has been completed.

The Precedence Diagram Method (PDM) allows for this and other situations. Besides the usual FS relationship, PDM permits the relationships of Start-to-Start (SS), Finish-to-Finish (FF), and Start-to-Finish (SF). It also allows for time lags in these relationships, such as lags between two starts, two finishes or a start and a finish.

These special relationships in PDM are described hereunder using the AON networks.

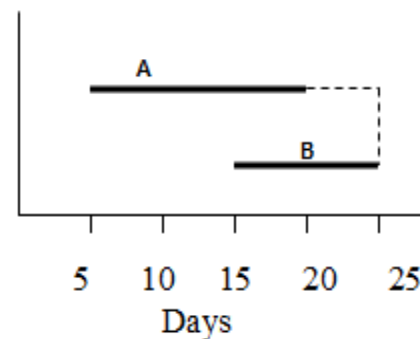
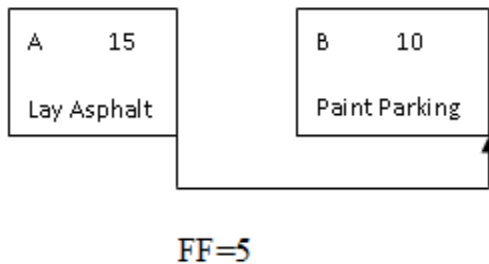
Start-to-Start, SS

In an SS relationship between two activities A and B, the start of B can occur 'n' days, at the earliest, after the start of its immediate predecessor, A. Suppose that a " stone masonry work" can start no sooner than 5 days after the start of " trench excavation", the network diagram and the associated Gantt chart for the two activities would appear as follows.



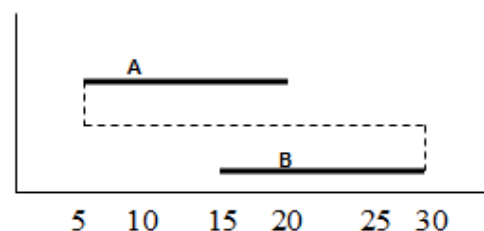
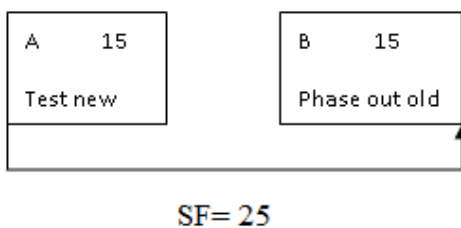
Finish-to-Finish, FF

In an FF relationship between two activities A and B, B will finish “n” days, at the latest, after A finishes. An illustration is given hereunder where “paint parking lines” (B) must be finished within 5 days after “Asphalt lay” (A) has been finished.



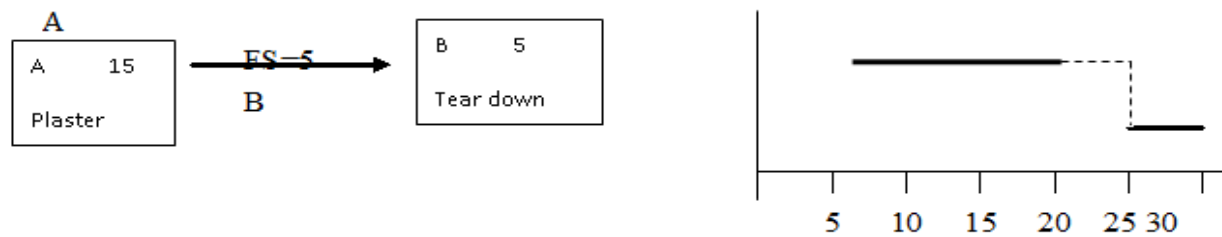
Start-to-Finish, SF

In an SF relationship, the finish of activity B must occur “n” days at the latest, after the start of activity A. For example, “phase out old system” (B) cannot be finished until 25 days after “test new system” begins.



Finish-to-Start, FS

In an FS relationship, the start of activity B can occur “n” days, at the earliest, after the finish of activity A. For example, “tear down scaffolding” (B) can start no sooner than 5 days after “plaster walls” is finished. Note that when “n = 0”, the FS relationship is the same as the one used in traditional AOA and AON network scheduling, wherein the start of the successor coincides with the completion of its latest predecessor, with no lag between them.



❖ The Performance Evaluation & Review Technique (PERT)

The main difference between CPM and PERT is that CPM is activity oriented while PERT is event oriented. In PERT the line connecting the circles represents activities and the circle itself represents an event, which marks completion of activity. PERT uses three time estimates, i.e. Optimistic, Most probable and Pessimistic. To find a single expected time the three time estimates can be compounded together as follows.

$$te = \frac{O + 4M + P}{6}$$

EXAMPLE:

2. The Bar Charts

Bar chart schedule is a graphical schedule relating progress of items of work to a time schedule. The column headed “hours” indicates the estimated no of labour – hours required for each activity. The column headed “weight” indicates the portion of the total project effort accounted for by each activity. Most frequently activities weighted 02 Birr value and labour hours.

Steps to draw bar charts

1. Divide the project into its job activities
2. Determine the activity durations
3. Try to arrange precedence, concurrence and successor activities

Weighting column is not always present on a bar chart; its presence is very useful when calculating cumulative project progress.

$$\text{Cumulative progress} = \sum_{i=1}^n (\text{activity progress})_i \times (\text{weight})_i$$

The degree to which the project breakdown may be carried can vary considerably, but certain basic factors affect the division to be made.

1. The type of work to be done and the labour classification, which will be doing the work.
2. The project divided with respect to its structural elements.
3. Division of the contract for assignment of responsibilities.
4. Location of the work both as to geographic and time position
5. Break down in conjunction with method of payment.

Bar chart has a major weakness in that it doesn't show the interrelationships and interdependencies among the various phases of the work, and there is no way of determining which operations actually control the overall time progress of the project.

No	Activity	Hours	Weight		Weeks									
1	Cleaning & Stripping	750	4.7	P	1	2	3	4	5	6	7	8	9	10
				A		20	70							
2	Drainage	150	0.9	P		46		9						
				A			60							
3	Sub grade	4200	26.4	P			30	1						
				A			16	4	65	8				
4	Base Coarse	4000	25.2	P			5	2						
				A					10	3	6	8		

										0	0	5		
5	Pave	6800	42.8	P						2	4	6	8	95
										0	5	5	0	
				A										

3.3 Scheduling with Resource Constraints

Cost-Time Trade-off and Project Crashing

In preparing the EST baseline schedule, we assumed an optimum resource level deployed to execute a certain activity. Though, this could be the 'best' trade-off between time and cost, sometimes it may be necessary to execute activities faster than the optimum time required, as usually is the case in catching up when project lag behind or when clients demand expedient finish of project for business or otherwise decisions. Such expedient execution of activities [projects] is termed as *crashing* and is bound to require additional resources. These resources might be additional labor, more equipment, and so on. Although shortening or "crashing" activity times can be expensive, doing so might be worthwhile. If a company faces costly penalties for being late with a project, using additional resources to complete the project on time might be economical. There may be fixed costs every day the project is in process. Thus, it might be profitable to use additional resources to shorten the project time and save some of the daily fixed costs. But what activities should be shortened? How much will this action cost? Will a reduction in the activity time in turn reduce the time needed to complete the entire project? Ideally, project managers would like to find the least expensive method of shortening the entire project.

The objective of crashing is to reduce the entire project completion time by a certain amount at the least cost possible. For each activity, there will exist a reduction in activity time and an associated cost incurred for that time reduction. However, for practicality purpose, there exists some minimum time period that an activity requires for execution irrespective of the resource amount deployed. Hence activity durations can't be reduced indefinitely.

Here, for simplicity, we will assume that costs increase linearly as the activity time is reduced from its expected to its crash value.

Let: Normal time = expected time for an activity

Crash time = shortest possible time for that activity

Normal cost = cost of completing the activity in normal time

Crash cost = cost of completing the activity in the crash time

$$\text{Crash cost per unit time} = \frac{\text{Crash cost}}{\text{time period}} = \frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal time} - \text{Crash time}}$$

Si No	Activity	Duration	Predecessor			Resource
1	1-3	4			3	5C,7L,2F
2	1-5	3			8	2C,4L,1F
3	1-7	5			0	5C,7L
4	3-5	4	1-3		3	8C,11L,3F
5	3-11	3	1-3		6	7C,9L
5	5-11	0	1-5,3-5			
6	5-13	4	1-5,3-5		3	4C,6L
7	7-9	5	1-7		0	5C,7L,3F
8	9-13	5	7-9		0	3C,5L
9	11-13	2	3-11,5-11		5	2C,4L,1F

Time-limited resource scheduling

As discussed above, there may arise a case that a project has to satisfy a strictly defined end date for such reasons as:

The project has a heavy time penalties

The project is part of another project with critical access dates;

The completion on time of the project is very crucial such as Olympic stadium for the games in such cases, project managers may need to crash activities to meet the completion deadline rather than use the optimum trade-off between time and resource. Such type of project which is very time sensitive are said to be scheduled on time limited scheduling techniques.

Ways of meeting dealing with deadlines other than crashing:

- ✓ Working overtime;
- ✓ Working on shifts;

- ✓ Increasing productivity by training, applying appropriate motivational factors such as 'job and knock' principles;
- ✓ Sub-contracting. If there are some special sub-contractors who are veteran in the trade to be executed, sub-contracting the job to them may save time as they have the best experience in doing the job and can do it in a lesser time.

Resource limited scheduling

Opposite to time limited scheduling, there may be some constraints such as resource unavailability [either the actual resources or the facilities associated with them], limited space and restricted access, health and safety requirements, etc in getting the optimum resource working in a project execution. In such cases, the project is said to be resource limited for optimum planning.

Resource constrained scheduling should be applied whenever there are limited resources available for a project and the competition for these resources among the project activities is keen. In effect, delays are liable to occur in such cases as activities must wait until common resources become available. To the extent that resources are limited and demand for the resource is high, this waiting may be considerable. In turn, the congestion associated with these waits represents increased costs, poor productivity and, in the end, project delays. Schedules made without consideration for such bottlenecks can be completely unrealistic.

Resource constrained scheduling is of particular importance in managing multiple projects with fixed resources of staff or equipment. For example, a design office has an identifiable staff which must be assigned to particular projects and design activities. When the workload is heavy, the designers may fall behind on completing their assignments. Government agencies are particularly prone to the problems of fixed staffing levels, although some flexibility in accomplishing tasks is possible through the mechanism of contracting work to outside firms. Construction activities are less susceptible to this type of problem since it is easier and less costly to hire additional

personnel for the (relatively) short duration of a construction project. Overtime or double shift work also provide some flexibility.

Resource oriented scheduling also is appropriate in cases in which unique resources are to be used. For example, scheduling excavation operations when one only excavator is available is simply a process of assigning work tasks or job segments on a day by day basis while insuring that appropriate precedence relationships are maintained. Even with more than one resource, this manual assignment process may be quite adequate. However, a planner should be careful to insure that necessary precedence's are maintained.

Resource constrained scheduling represents a considerable challenge and source of frustration to researchers in mathematics and operations research. While algorithms for optimal solution of the resource constrained problem exist, they are generally too computationally expensive to be practical for all but small networks (of less than about 100 nodes). The difficulty of the resource constrained project scheduling problem arises from the combinatorial explosion of different resource assignments which can be made and the fact that the decision variables are integer values representing all-or-nothing assignments of a particular resource to a particular activity. In contrast, simple critical path scheduling deals with continuous time variables. Construction projects typically involve many activities, so optimal solution techniques for resource allocation are not practical.

One possible simplification of the resource oriented scheduling problem is to ignore precedence relationships. In some applications, it may be impossible or unnecessary to consider precedence constraints among activities. In these cases, the focus of scheduling is usually on efficient utilization of project resources. To insure minimum cost and delay, a project manager attempts to minimize the amount of time that resources are unused and to minimize the waiting time for scarce resources. This resource oriented scheduling is often formalized as a problem of "job shop" scheduling in which numerous tasks are to be scheduled for completion and a variety of discrete resources need to perform operations to complete the tasks.

Reflecting the original orientation towards manufacturing applications, tasks are usually referred to as "jobs" and resources to be scheduled are designated "machines." In the provision of constructed facilities, an analogy would be an architectural/engineering design office in which numerous designs related tasks are to be accomplished by individual professionals in different departments. The scheduling problem is to insure efficient use of the individual professionals (i.e. the resources) and to complete specific tasks in a timely manner.

The simplest form of resource oriented scheduling is a reservation system for particular resources. In this case, competing activities or users of a resource pre-arrange use of the resource for a particular time period. Since the resource assignment is known in advance, other users of the resource can schedule their activities more effectively. The result is less waiting or "queuing" for a resource. It is also possible to inaugurate a preference system within the reservation process so that high-priority activities can be accommodated directly.

In the more general case of multiple resources and specialized tasks, practical resource constrained scheduling procedures rely on heuristic procedures to develop good but not necessarily optimal schedules. While this is the occasion for considerable anguish among researchers, the heuristic methods will typically give fairly good results. An example heuristic method is provided in the next section. Manual methods in which a human scheduler revises a critical path schedule in light of resource constraints can also work relatively well. Given that much of the data and the network representation used in forming a project schedule are uncertain, the results of applying heuristic procedures may be quite adequate in practice.

A Resource-Oriented Scheduling Procedure

Step 1: Rank all resources from the most important to the least important, and number the resources $i = 1, 2, 3, \dots, m$.

Step 2: Set the scheduled start time for each activity to the earliest start time.

For each resource $i = 1, 2, 3, \dots, m$ in turn:

Step 3: Start at the project beginning, so set $t = 0$.

Step 4: Compute the demand for resource i at time t by summing up the

requirements for resource i for all activities scheduled to be underway at time t .

If demand for resource i in time t is greater than the resource availability, then select the activity with the greatest late start time requiring resource i at time t , and shift its scheduled start time to time $t+1$.

Repeat Step 4 until the resource constraint at time t for resource i is satisfied.

Step 5: Repeat step 4 for each project period in turn, setting $t = t+1$.