

## PART II: CONSTRUCTION PLANNING AND SCHEDULING

### CONSTRUCTION TIME PLANNING

#### 1. PROJECT CONSTRUCTION PLANNING

Project construction planning includes the following inter-dependent components:

- *Construction Time Planning & Scheduling*
- *Resources and Cost Planning & Scheduling*

#### 2. CONSTRUCTION TIME PLANNING AND SCHEDULING

Construction Time Planning is the first step in the construction planning process. It includes the planning effort required to facilitate timely completion of a project. Construction Time Scheduling provides a working time-table of project activities for completion of the project within specified time. It is a direct consequence of the construction time planning process.

The steps involved in construction time planning and scheduling process are:

1. Develop Project Work Breakdown Structures (WBS)
2. Develop Activity List
3. Estimate Activity Durations
4. Establish Activity Logic Relationships
5. Define Project Base Calendars
6. Develop Project Time Schedule
7. Analyze and Adjust Project Time Schedule

Steps 1-5 will be covered in this handout. Steps 6-7 will be covered in next handout.

*Detailed Explanation of Construction Time Planning And Scheduling steps using Real-Time Construction Project - 100 Unit Housing Colony (Refer Lectures 12 ~ 15).*

#### **Step 1. Project Work Breakdown Structures (WBS):**

##### **1.1 Key Idea**

WBS provides the foundation for defining work as it relates to project objective and establishes the structure for managing the work to its completion.

A WBS is not a to-do list (consisting of everything that needs to be done on the project). Rather it is management structure.

##### **1.2 WBS Definition**

According to PMI:

A Work Breakdown Structure (WBS) is a deliverable-oriented grouping of project components that defines and organizes the total scope of the project; work not in the WBS is outside the scope of the project.

Stated in another way, a WBS is the hierarchy of work you must accomplish to complete a project. The WBS is structured in levels of work detail, beginning with the end result or product, and then divided into identifiable work elements. Each descending level in a WBS represents an increasingly detailed description of the project deliverables.

These definitions imply that a WBS has the following characteristics:

1. It is representative of work, and this work has a tangible result.
2. It is arranged in a hierarchical structure.
3. It provides a management structure.

### 1.3. WBS Levels

The WBS will include all work to be done by the primary organization. While generally the WBS consists of a five-level hierarchy describing the entire effort to be accomplished by the primary organization, that number may not be appropriate for all situations. The depth of a WBS is dependent upon the size and complexity of the project and the level of detail needed to plan and manage it.

The WBS levels may be broadly categorized into five major levels. These levels, arranged in a descending hierarchical order are:

Level 1: Program level

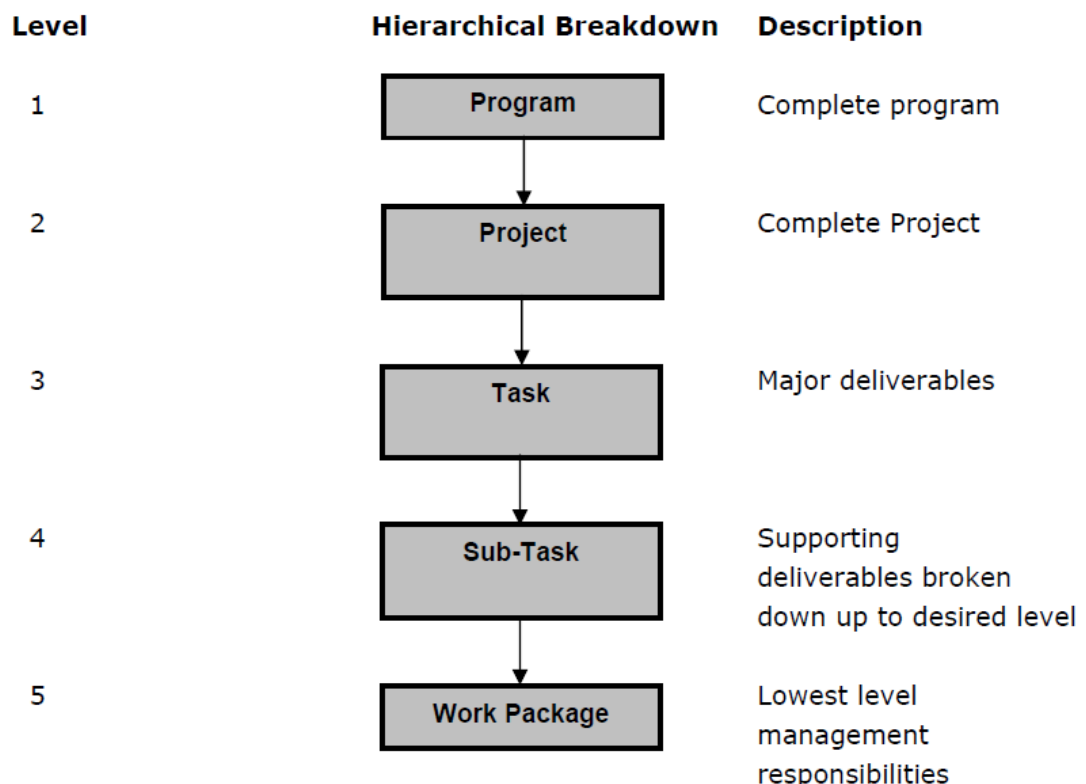
Level 2: Project level

Level 3: Task level

Level 4: Sub-Task Level

Level 5: Work Package level

A WBS is normally presented in chart form (see Fig. 1).



**Fig. 1.** Hierarchical Chart for WBS

The upper three levels of the WBS are normally specified by the client (as part of an RFP - Request For Proposal) as the summary levels for reporting purposes. The lower levels are generated by the Contractor for in-house control.

Project Control Levels	WBS Levels
Project Management	Program/ Project
Intermediate Managerial Levels	Task/ Sub-Task
Supervisor Levels	Work Package

**Fig. 2.** Project Control and WBS Levels

### 1.3.1. Program and Project Levels:

Program level defines the overall work program. A work program consists of two or more inter-related projects with overall time, cost and performance objectives and resource constraints. Each group of major works which can progress in a systematic manner, with minimal interference from other works, and which produces a major deliverable can be treated as a project. Each project is assigned time, cost and performance objectives and is provided with planned resources for accomplishing the project objectives. In the 100 Housing Units Residential Colony Project, each category of construction (Categories A to D) can be treated as a project (see Exhibit 2) while the whole work can be treated as a program.

The number of projects in a program varies with the nature and complexity of the program. Note that each project may comprise of one or more contract packages.

**1.3.2. Task and Sub-Task Levels:** A **task** represents a higher level significant work output within a project (for example, feasibility report which marks phase end deliverable for the feasibility phase of a project). Each task can further be decomposed in **sub-tasks** (for example, EIA study report, benefit-cost analysis report, etc). This hierarchical structure of task / sub-tasks establishes a management structure with desired level of management control at each level of project work.

### 1.3.3. Work Package Level:

According to PMI:

"A Work Package is defined as a deliverable at the lowest level of the work breakdown structure, when that deliverable may be assigned to another (work) manager to plan, execute and control." This may be accomplished by further decomposing each work package into activities.

There is an important difference in the last work breakdown structure level and an activity. Typically, a work package includes the outcomes of more than one activity from more than one department/ area of work. Therefore, the work package does not have duration of its own and does not consume resources and cost directly; the resources and cost for the work package are simply the summation of the resources and costs for all the activities constituting the work package.

*Note that the lowest element of a WBS is a work package, which represents the lowest management responsibility level desired on the project, which in turn represents the level of trust in the management team.*

Exhibit 1 shows a simplified WBS for the housing colony project.

#### **1.4. Uses and Effectiveness of WBS**

- 1. Represents complete scope of work in an organized manner.**
- 2. Sorts work in a hierarchical order.**
- 3. Identifies major deliverables and sub-deliverables.**
- 4. Develops a list of work packages.**
- 5. Thought process tool.** WBS helps the PM and the project team visualize exactly how the work of the project can be defined and managed effectively.  
Alternative ways of decomposing the work will be considered until an alternative is found with which the PM is comfortable.
- 6. Strategy Design tool.** WBS is a picture of the work of the project and how the items of work are related to one another.
- 7. Management database at various Levels.**
- 8. Structuring of work organization.** While WBS is developed, organizations, organizational units, teams and individuals are assigned responsibility for accomplishment of work components.
- 9. Integration tool.** WBS supports integrating responsibility for the various works with various responsibility units (organizations, departments, teams, individuals) by having a direct relationship between the WBS elements related to the *Organizational Breakdown Structure (OBS)* identified through the *Responsibility Assignment Matrix (RAM)*.
- 10. Work Budgeting.** WBS can be used for budget allocation on individual work components. Using the project roll-up approach, this budget allocation can be consolidated into establishing the overall project budget requirement.
- 11. Planning tool.** Using the lowest work package level of the WBS, time, resource and cost requirements of constituting activities are estimated; a work schedule is prepared; and deliverable dates and project completion are estimated.
- 12. Monitoring and Reporting tool.** Use of structure provides the opportunity to "roll up" (sum) the budget and actual costs of the smaller work items into larger work elements so that performance can be measured by organizational units and work accomplishment. These performance measurements can then be reported to senior management at various levels in the project organization.
- 13. Communication tool.** WBS defines communication channels and assists in understanding and coordinating many parts of the project. The structure shows the work and organizational units responsible and suggests where written communication should be directed. Problems can be quickly addressed and coordinated because the structure integrates work and responsibility.

### 1.5. WBS Development Procedure

Project WBS development is based on a technique called *decomposition*. Decomposition involves subdividing work into smaller, more manageable components arranged in a hierarchical order until the work is defined in sufficient detail to facilitate management control as well as development of project activities. WBS development involves the following major steps:

Step 1: Identify the projects in the program, if any. The projects should be defined in terms of independent major physical products of the program.

Step 2: Identify the major deliverables of each project. The major deliverables should always be defined in terms of how the project will actually be organized and managed. There are two approaches to be considered: **noun-type approaches** and **verb-type approaches**.

**Noun-type approaches** define the deliverable of the project work in terms of the physical components that make up the deliverable.

For example: the physical units (*areas* - A1, A2, A3; *sections* - M1, M2, M3; *building blocks* - Admin, CED, MED, Library)

**Verb-type approaches** define the deliverable of the project work in terms of the actions that must be done to produce the deliverable.

For example: the phases of the project life cycle (design, procurement, construction, handover), or the work specialty (civil, mechanical, HVAC, etc.).

Step 3: Decompose major deliverables to a level of detail appropriate for management and integrated control. Decide if adequate cost and duration estimates can be developed at this level of detail for each deliverable. For each deliverable, proceed to step 5 if there is adequate detail, to step 4, if not – this means that different deliverables may have different levels of decomposition.

Step 4: Identify constituent components of each deliverable (these are the subdeliverables or sub-tasks). As with deliverables, sub-deliverables should be described in terms of tangible, verifiable results to facilitate performance measurement. Divide until criteria in step 3 is achieved. Now you are at workpackage level.

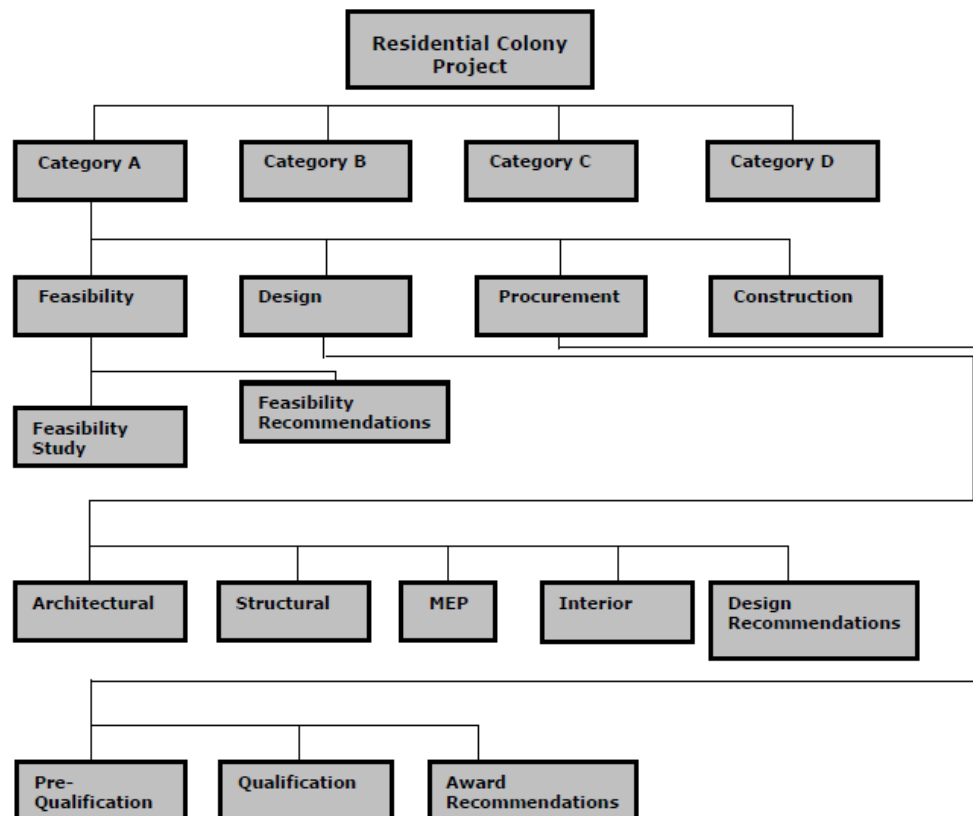
Every effort should be made to develop a WBS that is output-oriented in order to concentrate on concrete deliverables. If a WBS follows the organizational structure, the focus will be on the organization function and processes rather than the project output or deliverables.

### 1.6. WBS for the 100 Housing Unit Residential Colony Project

Exhibit 1 shows a sample WBS for the 100 Housing Unit Residential Colony Project. Note that this is not the only way to organize a WBS on this type of project. (*what other ways are possible?*).

*Exercise 1: The WBS in Exhibit 1 is not completely decomposed. After going through the next section (Activity List), refer back to this WBS and develop the missing levels.*

**Exhibit 1.** Work Breakdown Structure for Housing Colony Project



### Step 2. Develop Activity List:

#### 2.1 Activity

An activity is an identifiable and measurable short duration task that has a definite start and stop point, consumes resources and represents cost.

*Each activity is a control point. An Activity Manager is responsible for seeing that the activity is completed on time, within budget and according to technical specifications.*

The resources and cost for a work package are simply the summation of the resources and costs for all the activities constituting the work package. Thus, the **activity is the basic unit used for planning, monitoring and controlling the project.**

## 2.2. Activity Definition

Activity definition involves identifying and documenting the specific activities that must be performed in order to produce the work packages identified in the work breakdown structure.

### 2.2.1. Inputs to Activity Definition

- Work breakdown structure. Identification of work elements
- Historical information. What activities were actually required on previous, similar projects
- Constraints. Factors that will limit the project team's work options. These constraints may include: national economic policies, land reclamation constraints, unavailability of sophisticated equipment for site investigation and/or implementing construction methodologies.
- Assumptions. Factors that, for planning purposes, will be considered to be true, real, or certain.

### 2.2.2. Technique for Activity Definition

- *Decomposition of WBS work packages.*

### 2.2.3. Output from Activity Definition

- *Activity list*. The activity list must include all activities that will be performed on the project. A well prepared activity list allows the project team to separate out all activities of each trade, as well as identify the activity types (see section 2.3).  
A sample activity list developed for a Category D house (single storey normal finish house) of the residential colony project is shown in Exhibit 2.
- *Supporting Details*. Supporting details for the activity list should include documentation of all identified assumptions and constraints. For instance, if during excavation water tends to come out then it should be clearly mentioned as to whether or not the pumping of water is included within the scope of the project.

*Exercise 2: The Activity List in Exhibit 2 does not include any hammock activity. Include at least two hammock activities in the list.*

## 2.3. Activity Types

- *According to Nature of Activity*
- *According to Planning Consideration*

### I. According to Nature of Activity

#### 1. Production Activities

Production activities define the actual physical construction of the project.

Examples are:

- Erect concrete columns,
- Run electrical conduits, or

- Install sanitary fixtures.

If the project is composed of multiple units, floors, areas or sections, the activity would designate the activity location, such as run electrical conduits, 1st Floor.

## 2. Procurement Activities

Activities can also be categorized as procurement or purchasing activities. These are the activities that need to occur to get all of the materials, equipment and manpower to the job site. Bid procurement activities are also included

Examples are:

- Order tile,
- Approve flooring sample, or
- Prepare structural steel connection shop drawing
- Pre-qualify contractors

Most material procurement activities follow a logical sequence:

1. *Preparation of the submittal by the supplier or subcontractor;*
2. *Approval of the submittal by the owner and/or designer*
3. *Ordering and fabrication of the work item and*
4. *Delivery of the item to the job site.*

## 3. Administrative Activities

The third category of activity is the administrative activity. An activity the duration of which depends upon the logic and relationships existing between it and the various other activities is referred to as a hammock activity.

Examples are:

- Inspection activities by local officials or federal or regulatory agencies,
- Approval activities such as land approval and acquisition, or presentation before an architectural review commission,
- Management activities such as design or construction supervision.
- Identifying these activities is going to require the involvement of all the principal parties, since normally no single party knows all of the administrative steps that have to be followed. The construction team would be able to define the construction-related inspections, such as rough and finish plumbing inspections. The designer would identify any design reviews by third parties, such as those for seismic zoning requirements. The owner would be principally involved in securing financing and approvals for the project. The project/construction manager would be responsible for most, if not all, of the management activities.

## 4. Milestone Activities

A key event in the life of a project can be identified by the use of a milestone activity. Examples are:



- The prearranged shutdown of plant operations,
- The delivery of a certain floor of a building to a tenant, or
- A road to be opened by a specific date.

Unlike an activity, a milestone cannot be assigned to a responsibility unit and does not consume time or resources. A milestone is used to signify an important point in the life of a project so as to "flag" significant project accomplishments serving as a measure of project performance. For instance, delivery of a certain floor of a building to a tenant is an Intermediate milestone.

Commonly used milestones are the Start Milestone (e.g. Project Start) and the Finish Milestone (e.g. Project Handover).

## **II. According to Planning Considerations**

### **1. Task (fixed duration) *"scheduling of activity determines scheduling of resources"***

The assigned resources on the activity should be scheduled according to the activity's schedule.

For example, several activities must be done in the week before the completion of house. It doesn't matter whether the resources are available earlier than that week, or whether they will otherwise be scheduled for time off during that week - these activities must be scheduled during a specific time-period, and their scheduling controls the scheduling of their resources. Major construction activities fall in this category.

### **2. Resource Driven**

*"scheduling of activity is determined by the scheduling of resources"*

In some cases, resource availability is highly constrained.

For instance, a contractor has access to excavator for only three days in a week. This may be because he is sharing the excavator on another project. In such a case, all excavation activity on the project must be scheduled within the available days of excavator.

### **3. Hammock**

*"No specific duration, duration is calculated on the basis of relationships"*

Duration of some activities cannot be estimated using first principles.

For instance, what could be the duration of construction supervision? The answer is: It depends on the period of construction i.e. when the contract is awarded and when the project is handed over.

*Can you identify a few more hammock activities?*

**Exhibit 2.** Structured Sample Activity List for Residential Colony Project

WBS Levels	Activity	Activity Type 1 (Nature)	Activity Type 2 (Planning)
<b>1. Feasibility</b>			
<b>1.1. Feasibility Study</b>			
	Project Start	Milestone	Milestone
	Need Analysis	Production	Task
	Benefit/ Cost Analysis	Production	Task
	EIA	Production	Task
<b>1.2. Feasibility Recommendations</b>			
	Feasibility report preparation	Production	Task
	Analysis of feasibility report	Production	Task
	Yes/ No Decision	Milestone	Milestone
<b>2. Design</b>			
<b>2.1. Architectural Design</b>			
	Architectural Layout	Production	Task
	Architectural Design	Production	Task
<b>2.2. Structural Design</b>			
	Structural Layout	Production	Task
	Structural Design	Production	Task
<b>2.3. MEP Design</b>			
	Preliminary Design	Production	Task
	Detailed Design	Production	Task
<b>2.3. Interior Design</b>			
	Preliminary Design	Production	Task
	Detailed Design	Production	Task
<b>2.4. Design Recommendations</b>			
	Submission of Drawings & Specs	Production	Task
	Design Review	Production	Task
	Design Approval	Milestone	Milestone

WBS Levels	Activity	Activity Type 1 (Nature)	Activity Type 2 (Planning)
<b>3. Bid Procurement</b>			
<b>3.1. Contractor Pre-Qualification</b>			
	Receiving Pre-qualification	Procurement	Task
	Analysis of Pre-qualification	Procurement	Task
	Selection of pre-qualified	Procurement	Task
<b>3.2. Contractor Qualification</b>			
	Tender Floating	Procurement	Task
	Tender Analysis	Procurement	Task
	Tender Negotiations	Procurement	Task
<b>3.3. Contractor Award Recommendations</b>			
	Contract Terms and Conditions	Procurement	Task
	Award of Contract	Milestone	Milestone
<b>4. Construction</b>			
<b>4.1. Preparatory Works</b>			
	Mobilization	Production	Task
	Site Clearance	Production	Task
	Site Layout and Preparation	Production	Task
<b>4.2. Civil Structural Works</b>			
<b>4.2.1. Sub-Structure Works</b>			
	Excavation	Production	Task
	Foundations	Production	Task
	Stub Columns	Production	Task
	Plinth Beams	Production	Task
	UGWT	Production	Task
<b>4.2.2. Super-Structure Works</b>			
	Columns	Production	Task
	Beams/ Slabs	Production	Task
	OHWT	Production	Task
<b>4.3. MEP Works</b>			
<b>4.3.1. Preliminary</b>			
	Rough Electrical	Production	Task
	Rough Plumbing	Production	Task
<b>4.3.2. Finishing</b>			
	Electrical Fittings	Production	Task
	Plumbing Fixtures	Production	Task
<b>4.4. Civil Finishing Works</b>			
<b>4.4.1. Internal Works</b>			
	Block Masonry	Production	Task
	Door/ Window Frames	Production	Task
	Plaster	Production	Task
	Door/ Window Panels	Production	Task
	Flooring	Production	Task
	Paint	Production	Task
<b>4.4.2. External Works</b>			
	Block Masonry	Production	Task
	Plaster	Production	Task
	Fixing of Main Gate	Production	Task
	Paint	Production	Task
<b>5. Handover</b>			
	Punch List	Production	Task
	Project handover	Milestone	Milestone

### **Step 3. Estimate Activity Durations:**

Activity duration estimating involves assessing the **work time** likely to be needed to complete each identified activity

Duration for every activity is needed so that planning of the project can be done with respect to time.

#### **3.1 CONCEPT**

- **Work Time (Duration):** Work time is the business time required to complete an activity. This does not include weekends, holidays, or other non-work time, but includes provision for any anticipated interruptions.
- **Calendar Time:** Calendar time is the total time required to complete an activity considering the work as well as non-work periods, and including provision for any anticipated interruptions.

For example, a client has an activity that requires him to send a document to a government agency, where it would be reviewed, approved, and then returned. The client has done this on several previous occasions, and it normally took about 10 business days before the document was back in client's office. The government agency works for 5 days in a week and the client is sending the document on Monday morning. Now:

- a. What is the duration? The answer is 10 days.
- b. What is the calendar time? The answer is 12 days (Mon-Fri, Sat, Sun, Mon-Fri).

### 3.2. ESTABLISHMENT OF ACTIVITY DURATION

Activity duration can be estimated with the aid of a computer (e.g., by using excel spreadsheet or project management software) or with manual techniques.

Manual techniques are often more effective on smaller projects. Manual and automated techniques may also be used in combination.

### 3.3. INPUTS TO ACTIVITY DURATION ESTIMATION

- **Quantity of Work:** The amount of work that needs to be performed; e.g. 10,000 cft of excavation, 2000 cft of concreting, 1000 sq-ft of block masonry, etc. This information is obtained from detailed BOQ or work estimates in conjunction with construction drawings.
- **Execution Methodology:** The execution methodology drives the resource requirement on the activity. For example, the activity of placing concrete in the foundation of a large building can be done in any of the following ways - manually, using crane and bucket arrangement, pumping by concrete pumps or transporting by a conveyor system. The time and cost for each of these methods will differ considerably. The choice of the method of execution of an activity depends upon the past experience, the market availability of appropriate resources, the resources available with the contractor, the technological and methodological constraints, and the cost-benefit analysis of the various methods of production. In short, it is the method of production that dictates the resources required for accomplishment of an activity.
- **Resource Requirement:** What type of resources (manpower, equipment and material) are required and in what quantity? Resource estimates are normally made using the planning norms developed from:
  - Organizational records of previous projects
  - Project team knowledge and experience
  - Commercially available databases (if any)
  - Expert advice

- **Resource Productivities:** The capabilities of the humans and equipment resources assigned to activities - e.g. if both are assigned full-time, a senior staff member can generally be expected to complete a given activity in less time than a junior staff member. Resource productivity is normally determined from:

- Organizational records of previous projects
- Project team knowledge and experience
- Commercially available databases (if any)
- Expert advice
- Field research

Note that lack of focus, temperature variation, untimely breaks, socializing, coordination issues, rework due to errors, lack of supervision, etc. account for reduced resource work input in a work day.

*Average productivity is usually taken at 65-75% of maximum productivity.*

- **Time Contingency:** This includes any possible time variation that needs to be incorporated for any anticipated and unanticipated interruptions, e.g. Interruptions might include a phone call with a question to be answered, an equipment breakdown, power interrupts, random events of nature, untimely delivery of material, bad weather forecasts, absenteeism, strikes, etc. Few of these interruptions may be anticipated (e.g. bad weather forecast, procession, strike etc.) while others may be unanticipated (e.g. random event of nature).

*About one-third of the time is normally spent on interruptions.*

### 3.4. TECHNIQUES FOR ACTIVITY DURATION ESTIMATION

The following techniques can be used for initial planning estimates:

- One-time estimate
- Three-times estimate
- **One-time estimate** In most of the construction works, it is generally possible to assess the duration of an activity with reasonable certainty by using organizational planning data records, experience, commercially available databases, or expert advice. **The one-time estimate for activity durations is usually used for Production activities.**

$\text{Duration of an activity} = \frac{\text{Quantity of work}}{\text{Production Effort}}$
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where,

Production Effort = Number of resource teams x productivity of each resource team

Example

How many hours will be needed to excavate 10,000 cu-ft with the provided data?

Excavator's Productivity = 1000 cu-ft/hr

Number of Excavators = 2

Contingency factor = 0.2

$$\text{Duration} = \frac{10,000}{1000 \times 2} \text{ cu ft} = 5 \text{ hours}$$

Now, adjust for contingency:

$$\text{Adjusted Duration} = 5 \times 1.2 = 6 \text{ hours}$$

*If the number of excavators increases from 2 to 4, will the duration become 6 hours?*

- **Three-time estimate**

For this method you are calling on the collective memory of professionals who have worked on similar activities but for which there is no recorded history, or if there is a recorded history, the current conditions are too different.

Here activity duration is considered a random variable, which means that if it were possible to repeat the activity several times under identical circumstances, duration times would vary. That variation may be tightly grouped around a central value, or it might be widely dispersed.

To use three-time estimate technique, three estimates of activity duration: optimistic, pessimistic, and most likely (See Fig. 3.) are needed. The optimistic time is defined as the shortest duration one has or might expect to experience given that everything happens as expected. The pessimistic time is that duration that would be experienced (or has been experienced) if everything that could go wrong did go wrong and yet the activity was completed. Finally, the most likely time is that time usually experienced (most expected).

The following relation is used to calculate the expected duration of such an activity:

$T_e = \frac{a+4m+b}{6}$
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where,  $T_e$  = expected activity duration

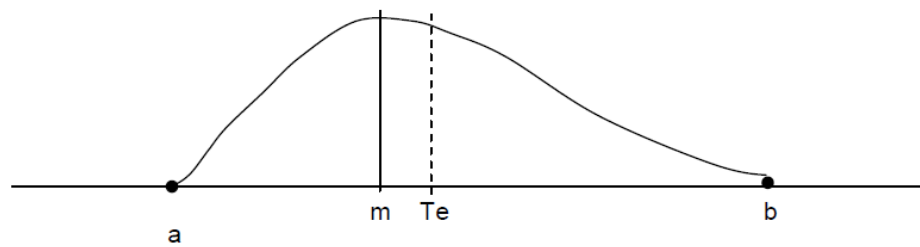
$a$  = optimistic time,  $b$  = pessimistic time,  $m$  = most likely time

The three-time estimate is usually used for some types of Procurement and Administrative activities. It can effectively be used in certain areas of construction projects where major uncertainty in duration estimation exists.

Some of these are as follows:

- The sanctioning of a government project
- The necessary project approvals
- The feasibility stage of a project

- The closeout stage of a project
- Procurement of long-lead items



**Fig. 3. Three-Time Estimate**

Example: Consider the activity of sanctioning of a government project. It has to pass through many channels and depends upon many factors.

Assume that the sanction is most likely to take 8 weeks, and if all goes well, the earliest it can happen is 6 weeks, but in any case, it will certainly come through in 16 weeks. The expected duration of the activity can then be calculated as follows:

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

### 3.5 ACTIVITY DURATION ESTIMATION PROCEDURE

Duration of each activity is evaluated independent of the others. The various stages in duration estimation of a construction activity can be identified as follows:

1. Estimating the quantity of work. These estimates are worked out from the engineering drawings and BOQ of the project.
2. Assessing the employment of resources. Based on the execution methodology, assess the resources that can be employed effectively. Normally, in construction, resources are employed in teams.
3. Deciding the labor and equipment productivity. These values vary with place, environment and projects. If resources are employed as teams, this step means deciding resource team productivities.
4. Estimating the activity duration - one-time or three-time.
5. Rounding up the duration to nearest value.
6. Making duration adjustments for any anticipated or unanticipated contingency.

### 3.6. Output from Activity Duration Estimating

Activity duration estimates. Quantitative assessments of the likely number of work periods required for completing an activity.

For the residential colony project, the activity duration estimates for a Category D house are shown in Exhibit 3.

Basis of estimate. Documentation of the assumptions used for developing the estimates.

Activity list updates

**Exhibit 3.** Activity Duration Estimates for a Category D House

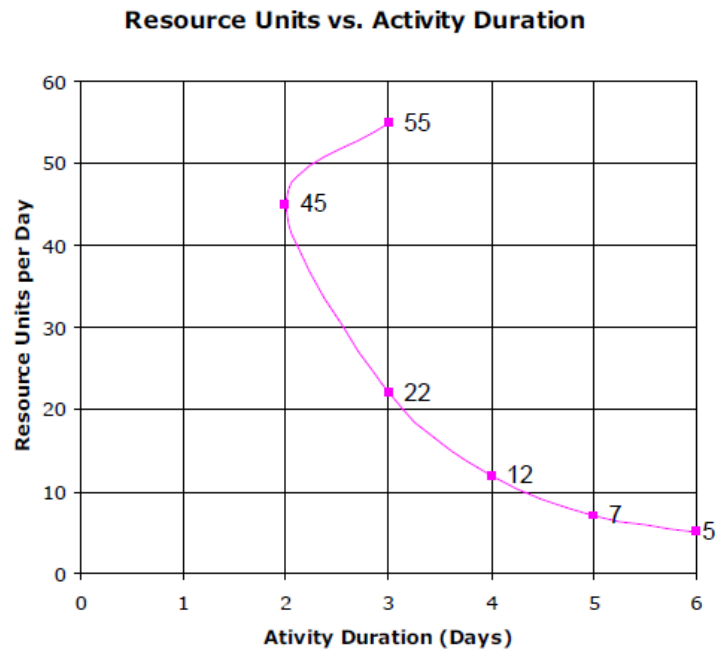
Activity ID	Activity	Duration
1	Project Start	0
2	Need Analysis	14
3	Benefit/ Cost Analysis	21
4	EIA	14
5	Feasibility report preparation	21
6	Analysis of feasibility report	7
7	Yes/ No Decision	0
8	Architectural Layout	14
9	Architectural Design	21
10	Structural Layout	14
11	Structural Design	21
12	Preliminary MEP Design	7
13	Detailed MEP Design	14
14	Preliminary Interior Design	7
15	Detailed Interior Design	14
16	Submission of Drawings & Specs	7
17	Design Review	7
18	Design Approval	0
19	Receiving Pre-qualification Documents	14
20	Analysis of Pre-qualification Documents	14
21	Selection of pre-qualified contractors	7
22	Tender Floating	14
23	Tender Analysis	14
24	Tender Negotiations	14
25	Contract Terms and Conditions	7
26	Award of Contract	0
27	Mobilization	14
28	Site Clearance	7
29	Site Layout and Preparation	7
30	Excavation	14
31	Foundations	14
32	Stub Columns	7
33	Plinth Beams	7
34	UGWT	14
35	Columns	7
36	Beams/ Slabs	21
37	OHWT	21
38	Rough Electrical	14
39	Rough Plumbing	14
40	Electrical Fittings	21
41	Plumbing Fixtures	21
42	Block Masonry – Internal	21
43	Door/ Window Frames	14
44	Plaster – Internal	28
45	Door/ Window Panels – Internal	7
46	Flooring	28
47	Paint – Internal	14
48	Block Masonry – External	7
49	Plaster – External	7
50	Fixing of Main Gate	7
51	Paint – External	14
52	Punch List	14
53	Project handover	0

### 3.7. ACTIVITY DURATION AND RESOURCE VARIATION

- *There are diminishing returns for adding more resources.*
- *There is a maximum loading of resources on an activity to minimize the activity duration, and that by adding another resource you will actually begin to increase, the duration.*
- *There is a minimum loading of resources needed on an activity or else it can not be performed*
- *There is not necessarily an (inverse) linear relationship between the amount of resource assigned to an activity and its duration.*



Fig. 4 shows what the four points identify.



Explanation of above four points:

Duration of an activity is influenced by the amount of resources scheduled to work on it. Adding more resources to hold an activity duration within the planning limits can be effective. This is called crashing an activity. For example, suppose you are in a room where an ordinary size, four-legged chair is in the way. The door to the room is closed. You are asked to pick up the chair and take it out of the room into the hallway. You might try to do it without any help, in which case you would perform the following steps:

1. Pick up the chair;
2. Carry it to the door;
3. Set the chair down;
4. Open the door;
5. Hold the door open with your foot as you pick up the chair;
6. Carry the chair through the door and
7. Set the chair down in the hallway.

Suppose you double the resources. We'll get someone to help you by opening the door and holding it open while you pick up the chair and carry it out to the hallway. With two people working on the activity, you'd probably be willing to say it would reduce the time to move the chair out into the hall.

Doubling the resources sounds like a technology breakthrough in shortening duration. Let's try doubling them again and see what happens.

Now, we've got four resources assigned to the activity. The activity would go something like this: First, you hold a committee meeting to decide roles and responsibilities. Each person would like to get equal

credit, so each one grabs a leg of the chair and tries to go through the door, but they all get stuck in the door. (By the way, there's nobody left to open the door because each of the four resources is dedicated to one leg of the chair.)

You have reached the crash-point of the activity. The crash-point is that point where adding more resources will increase activity duration. *The project manager will have to consider the optimum loading of a resource on an activity.*

Another consideration for the project manager is the **amount of reduction in duration that results from adding resources**. The relationship is not linear. Consider the chair example again. Does doubling the resource cut the duration in half? Can two people dig a hole twice as fast as one? Probably not. The explanation is simple. By adding the  $n$ th person to an activity, you create the need for  $n$  more communication links.

Who is going to do what? How can the work of several people be coordinated? There may be other considerations that actually add work. To assume that the amount of work remains constant as you add resources is simply not correct. New kinds of work will emerge from the addition of a resource to an activity. For example, adding another person adds the need to communicate with more people and increases the duration of the activity.

A last consideration for the project manager is the **impact on risk from adding another resource**. If we limit the resource to people, we must consider the possibility that two people will prefer to approach the activity in different ways, with different work habits, and with different levels of commitment. The more people working on an activity, the more likely one will be absent, the higher the likelihood of a mistake being made, and the more likely they will get in each other's way.

### 3.8. HOW AND WHERE TO ACCOUNT FOR CONTINGENCIES

*Increase the durations of those activities that control the project (critical activities) and that are likely to be affected during the life of the project.*

### 3.9. IMPORTANT GUIDELINES FOR ACTIVITY DURATION ESTIMATION

1. Activity duration estimation should be done preferably, by the person responsible for its performance.
2. Each activity should be evaluated independently of all the others. For a given activity, assume that materials, labor, and equipment will be available when required and in whatever amounts required (Recall task).
3. Duration estimation should be based on the preferred method of execution considering current practices and prevailing work conditions.

4. Assume that activity will be performed in an organized manner.
5. For each activity, assume a normal level of manpower and equipment. Based on experience and research, normal/ standard crew size can be defined.
6. A normal workday (usually 8 hours/ day) is assumed. Overtime or multiple shifts are not considered unless this is standard procedure or part of a normal work-period.
7. Use consistent time units throughout (workhours, workdays, shifts, workweeks, workmonths, etc.).
8. Expert judgment guided by historical information should be used whenever possible. Durations are often difficult to estimate because of the number of factors that can influence them (e.g., resource type and number, resource productivity).
9. Time contingencies and practical problems should be considered, because we are not living in PERFECT WORLD.
10. A minimum and maximum limit on activity durations allow for effective monitoring:
  - A larger duration activity (e.g. "build foundation") would undoubtedly simplify the project plan, but it wouldn't be very helpful in controlling the work.
  - A smaller duration activity (e.g. "place rebar # 1000") would maximize the effort necessary to create and update the project plan, while providing maximum control in the construction work.
  - In practice, we look for a compromise.

#### **Step 4: Establish Activity Sequencing/ Logic Relationships**

Activity sequencing involves identifying interactivity dependencies/ relationships. Activities must be sequenced accurately in order to facilitate development of a realistic and achievable schedule.

#### **4.1. ESTABLISHMENT OF ACTIVITY SEQUENCING**

Sequencing can be performed with the aid of a computer (e.g., by using project management software) or with manual techniques. Manual techniques are often more effective on smaller projects. Manual and automated techniques may also be used in combination.

#### **4.2. INPUTS TO ACTIVITY SEQUENCING**

- ***Activity list***
- ***Mandatory dependencies (Hard Logic)***

Mandatory dependencies are those that are inherent in the nature of the work being done. They often involve physical limitations. In a road project, for instance, placing of base course is impossible without sub base placing.

- ***Discretionary dependencies (Soft/Preferred Logic)***

Discretionary dependencies are those that are defined by the project management team based on knowledge of:

- "Best practices".
- Some unusual aspect of the project where a specific sequence is preferred even though there are other acceptable sequences.

- **External dependencies**

External dependencies are those that involve a relationship between project activities and non-project activities. For example, environmental hearings may need to be held before site preparation can begin on a project.

- **Constraints**

- **Assumptions**

### 4.3. TECHNIQUES FOR ACTIVITY SEQUENCING

To depict the logic dependencies amongst activities, a project network diagram is developed using either the Arrow Diagramming Method or the Precedence Diagramming Method.

#### 4.3.1. Arrow Diagramming Method (ADM)

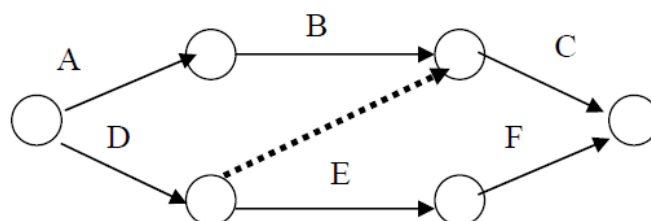
A project network drawn using ADM is built up from three main symbols:

- full arrows that represent activities;
- nodes that correspond to events and
- dummy arrows for logical sequences.

This technique is also called activity-on-arrow (AOA) diagramming method.

ADM can be done manually or on a computer. Fig. 5 which shows a simple project network diagram drawn using ADM is based on the given project data.

Activity ID	Predecessor
A	-
B	A
C	B, D
D	-
E	D
F	E

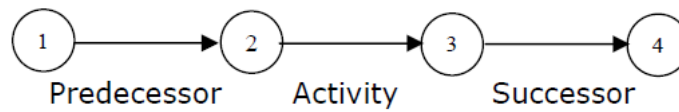


**Fig. 5.** Network Logic Diagram Drawn Using ADM

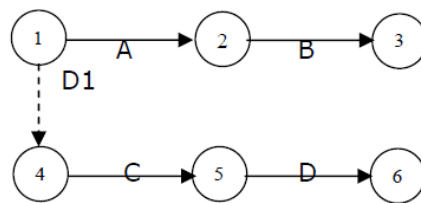
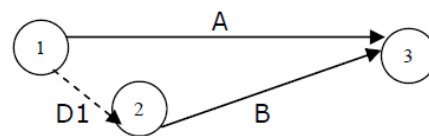
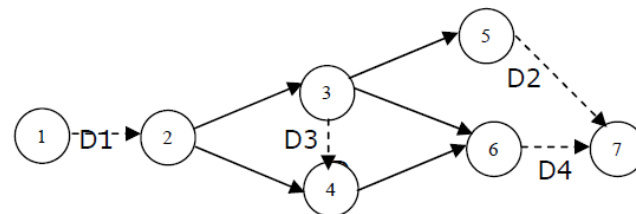
**Important Terms to Identify:**

Predecessor (Preceding Activity) → Activity immediately before

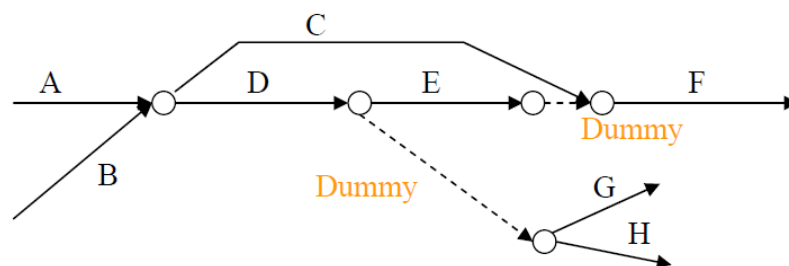
Successor (Succeeding Activity) → Activity immediately following

**Important parts of an ADM/AOA Network:**

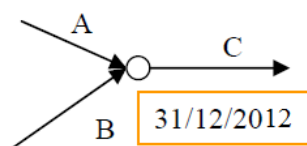
- A full arrow shows an activity and hence must have an ID and duration.
- The start and finish of an activity are events; they are represented as numbered circles called nodes. An event represents the achievement of a certain stage in the development of a project. It is defined as 'a state (a moment in time) in the progress of a project after the completion of all preceding activities but before the start of any succeeding activity.'
- The length of an arrow has no significance: it is not drawn to scale.
- The direction of arrow shows the direction of the activity in time, the arrowhead indicating the end of the activity.
- The term start event means an event with succeeding but no preceding activities and end event means an event with preceding but no succeeding activities.
- Some events may represent "milestones" which indicate that they have some particular significance to the planner. Usually the start, the finish and the completion of major phases of the project will be called milestones.
- **Dummies:** Dummies are activities with zero time duration represented by broken arrows. The standard definition of dummy is 'a logical link, a constraint which represents no operation.' It is used for one or more of the following:
  - To express logic i.e. sequence of events (Fig. 6.a);
  - To provide a unique numbering for each activity i.e. to prevent two or more activities from having the same i (start node) and j (end node) numbers (Fig. 6.b). (This is particularly required when developing the ADM on computer) and
  - To ensure a single start event and a single end event for a project network (Fig. 6.c).

**Fig. 6.a.** Logic Dummy**Fig. 6.b.** Numbering Dummy**Fig. 6.c.** Start or Finish Dummy**Using dummies efficiently**

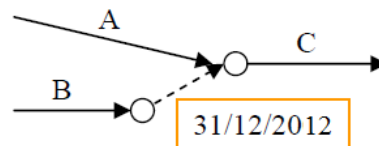
1. Avoid redundant dummies when dependencies are clear



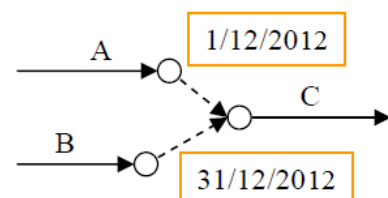
2. For clarity in defining some milestones



What does this milestone mean?



What if the milestone is for B?

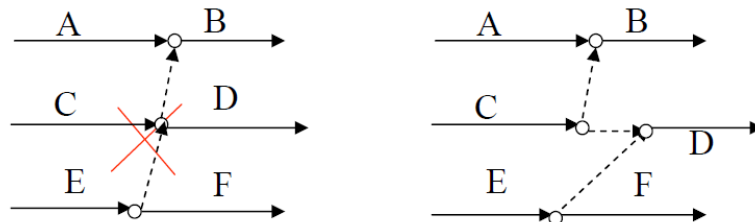


What if the milestones are for A and B both?

**Using dummies to resolve dependencies**

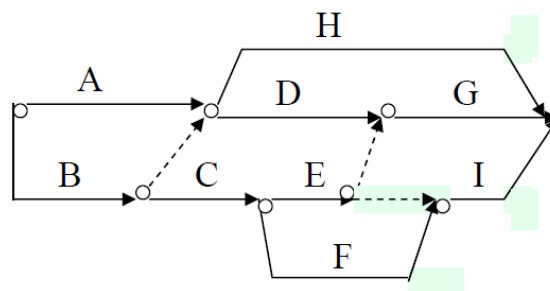
Example 1:

Activity	Succeeding activities
A	B
C	B and D
E	D and F



Example 2:

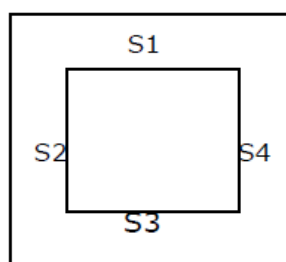
Activity	Succeeding activities
A	D, H
B	C, D, H
C	E, F
D	G
E	G, I
F	I

**ADM Activity Relationship:**

ADM only uses Finish-to-Start (FS) activity relationship.

- FS Activity starts when predecessor has finished
- Most commonly used relationship
- Default relationship for all project management software
- For instance, column starts when foundation has finished.

**Example Project Network using ADM Diagramming:** Consider part of a project in which a square footing is to be built as shown in Fig. 7.

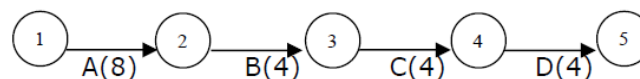


**Fig. 7. A Wall Footing**

This requires the following items of work (activities):

Activity ID	Activity Description	Duration (Workdays)
A	Excavate	8
B	Build and Place Formwork	4
C	Place Rebar	4
D	Place Concrete	4

The ADM network for this part of the project is shown in Fig. 8.a.

**Fig. 8.a. ADM for Footing**

From this example, it can clearly be seen that letting the work to proceed on more than one activity at a time would allow for efficient management of time, resource and budget.

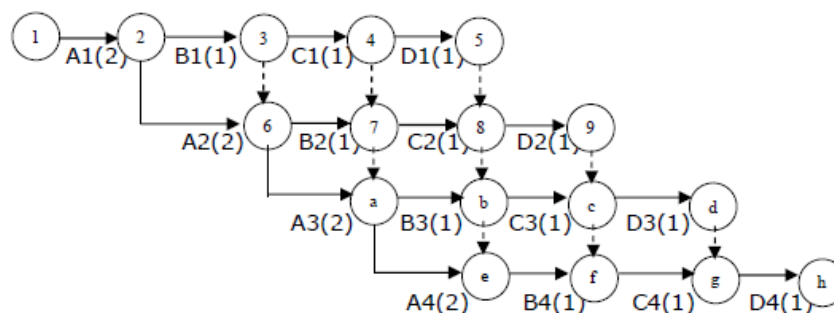
After side S1 is excavated, S2 can be excavated while S1 is being formed. Later, the rebars can be placed for S1 while S2 is being formed and S3 is being excavated, and so on.

### Defining activities in smaller units allow overlapping of activities.

Revised activity list:

Activity ID	Activity Description	Duration (Workdays)
A1	Excavate S1	2
B1	Form S1	1
C1	Place Rebars for S1	1
D1	Place Concrete for S1	1
A2	Excavate S2	2
and so on...		

The revised ADM network for this part of the project is shown in Fig. 8.b.

**Fig. 8.b. Arrow Diagram (Revised)**



**Advantages of ADM/ AOA Network:**

- It consists events. Events can be used to depict milestones. Efficient use of dummies can allow precise identification of milestones.
- The main advantage of ADM diagrams is the realistic approach of having arrows to represent activities that endure in time, whereas nodes (equivalent to points) show the points in time at which activities begin and end.

**Disadvantages of ADM/ AOA Network:**

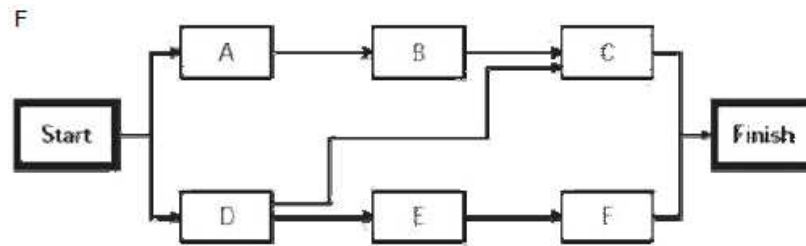
- Arrow notation uses an implicit finish-to-start relationship between dependent activities; i.e. when all arrows entering a node are complete, all arrows leaving may start. Two activities, such as the installation of reinforcing steel in a slab and the addition of conduits and other inserts in the same slab, may be required to be performed concurrently, but the network schedule would probably be able to show them only as being performed in parallel, with their starts requiring the completion of previous activity(s) and their completions constraining the beginning of later work. Or, the network might resort to showing the activities in sequence, with steel placement first, followed by conduit placement; such a representation may only be partially correct, with a small amount of steel actually being installed prior to start of conduit installation. In nearly all cases, it is simply impractical to break the project into so many detailed components as would allow reality to be depicted exactly. Actually, the finish-start constraint, while being unrealistic at times, does not cause us any unsolvable problems, but it does require us to be more careful in defining our activities and generally causes an unnecessarily larger number of activities to be needed for a given project.
- There can be no time lapse between the finish of preceding activity and start of succeeding activity; since nodes are events in time with zero duration.
- Finish-to-start constraint in ADM may require the use of dummy activities to define all logical relationships correctly. This makes the network unnecessarily complex as well as error prone.

**4.3.2. Precedence Diagramming Method (PDM)**

This is a method of constructing a project network diagram using:

- nodes to represent activities and
- full arrows to show the dependencies.

Fig. 9. shows a simple project network diagram drawn using PDM. This technique is also called activity-on-node (AON) and is the method of choice for most project management software packages (*why?*). Like ADM, PDM can be done manually or on a computer.



**Fig. 9.** Network Logic Diagram Drawn Using PDM

Do you think Figs. 5 and 9 represent the same project network? Which one seems to be a better representation and why?

#### **Important parts of a PDM/AON Network:**

- In a PDM diagram, a node - the "rectangular box", represents an activity and the "links" - the arrows, connect activities.
- Dummies can be forgotten, almost. Only a starting or ending dummy will be used, if needed, to ensure that there is a single start and a single finish activity for the project.

#### **Precedence Relationships:**

In an actual construction project, especially fast track projects, many activities have relationships that are not easily expressed with traditional **Finish-to-Start logic** which requires that one activity must finish before the following one can start. To overcome this limitation presented by ADM, PDM allows for four types of dependencies or **precedence relationships**. This gives more flexibility and ease in realistically identifying and defining the activity relationships, thereby allowing for a better model of the construction process. Unlike the traditional Finish-to-Start logic, all precedence relationships allow for activity overlapping and hence are most useful in fast track projects.

#### *How can we overlap activities?*

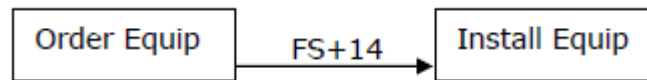
Activities can be overlapped by using four precedence relationships - Finish-to-Start (FS), Start-to-Start (SS), Finish-to-Finish (FF) and Start-to-Finish (SF).

#### **Precedence Relationships with Lead-Lag Factor:**

Any of the precedence relationship between two activities may require specification of a time lead or a time lag in order to accurately define the relationship. PDM, in addition to using different relationships, allows use of lead-lag factors to indicate the amount of time that must expire before the action expressed by the relationship can be performed.

For instance, in the traditional FS relationship, an activity can start immediately when predecessor has finished - this is equivalent of a lead lag factor of 0 because zero time was **required** between finish of first activity start of latter. In precedence diagramming, we can assign a lead-lag factor of any real number (even a percentage of duration).

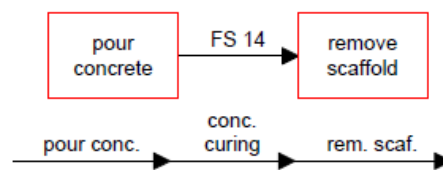
A positive value of lead-lag factor means a lag i.e. "wait", whereas a negative value indicates a lead. A zero value for the lead-lag factor represents **no time lapse needed** between two activities. For example, the planning team desires that there should be at least a two-week lapse between ordering a piece of equipment and installing it. This relationship may be represented as follows:



### Explanation of Precedence Relationships:

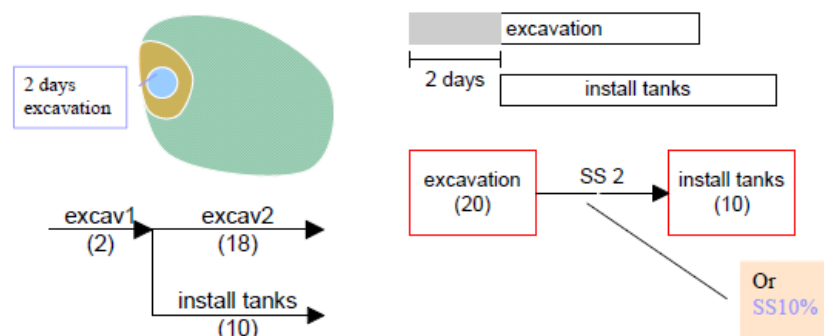
#### 1. Finish to Start

- Traditional I-J relationship
- Succeeding activity cannot start until minimum time has lapsed after the preceding activity has been completed



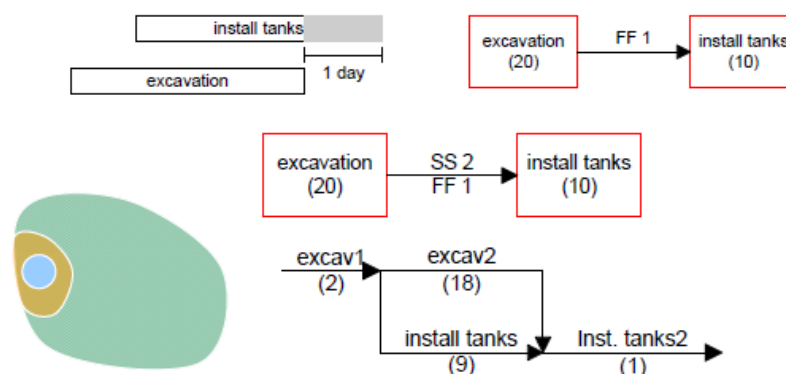
#### 2. Start to Start

Minimum time that must be completed on the preceding activity prior to start of successor



#### 3. Finish to Finish

- minimum time that must remain to be completed on succeeding activity after completion of predecessor

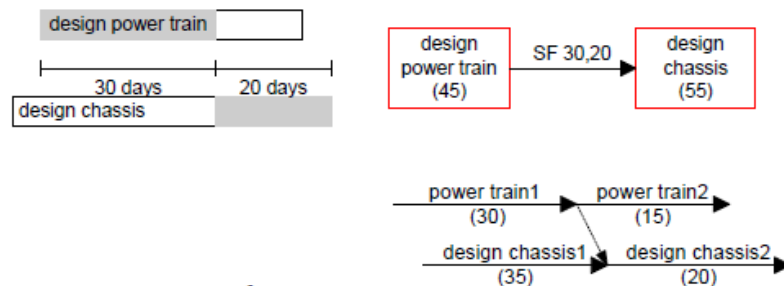


## 4. Start to Finish

- minimum time that must transpire from start of predecessor to completion of successor
- Note that this relationship is ***not the reverse of Finish to Start***.

*Example:*

- To complete chassis design (55 days) requires:  
     preliminary design of power train (30 days)  
     takes another 20 days  
     Power train design can proceed as usual (45 days)

**Important comment on precedence relationships:**

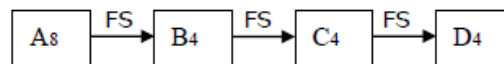
Any precedence relationship (with or without lead-lag factor) always specifies a lower bound of time.

*Can you interpret the following relationships between A and B?*

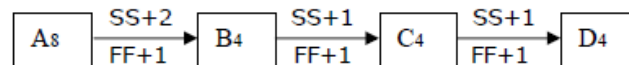
1. FS B can start at the same time or any time after finish of A
2. FS+7 B can start at least 7 days after finish of A
3. SS+2 B can start at least 2 days after start of A
4. FF+30 B can finish at least 30 days after finish of A
5. FS-3 B can start at least 3 days prior to the finish of A
6. SF+3 B can finish at least three days after start of A

**Example Project Network using PDM/ AON Diagramming:**

Consider the same square footing as was shown in Fig. 5. The PDM network for the same part of the project is given in Fig. 10.b.



**Fig. 10.a.** Conventional AON Diagram for Footing



**Fig. 10.b.** PDM Diagram for Footing

*Do you think PDM Diagram is a more efficient and realistic representation of the project network (as compared to conventional network)?*

**Advantages of PDM Network:**

- Dummies are eliminated. Learning the significance and proper usage of dummies requires time and experience and besides increasing complexity, dummies may lead to false dependencies that are a real hazard.
- It is a more realistic model for construction process as it allows for multiple logic relationships: start-start, finish-start, finish-finish and start-finish.
- The arrow that connects two activity nodes can have a time duration. This feature tends to reduce the number of activities that must be included in the network by allowing relationships in addition to "finishstart" and lead-lag factor.
- Many managers agree that concept of activity-on-node is easier to grasp than that of activity-on-arrow network. It is also easier to modify and correct a node diagram than an arrow diagram.
- Each activity can be assigned a single unique number, which can be used to classify the work by cost code, location, and the like.

**Disadvantages of PDM Network:**

- Events - point in time represented by circles on an activity-on-arrow network - are eliminated, and for some projects events are of major importance (recall that events may represent milestones).
- The main drawback of Node diagrams is the confusion caused by having symbols (equivalent to points) to represent activities that endure in time, whereas lines show the points in time at which activities begin and end.

**Final Comments on Arrow and Node Networks:**

- The method for developing the network in either of the two cases is somewhat different.
- The final networks should represent same project logic, since the beginning and ending times for each activity and the project logic is obviously independent of the kind of network representation technique used.

**4.4. OUTPUTS FROM ACTIVITY SEQUENCING**

- **Project network diagram.** A project network diagram is a schematic display of the project's activities and the logical relationships (dependencies) among them.
- **Activity list updates.** Dividing or redefining activities so that the relationships are correctly diagrammed.

### **Step 5: Define Project Base Calendars**

A base calendar defines the work period of a project organization. *Project Base Calendars cumulatively define the working and non-working periods of the project activities with respect to the performing organization(s).*

*Do we need more than one calendar for a single project?*

Yes!

*Why?*

Any construction project normally involves a number of organizations working on it. For instance, for the residential colony project under consideration, the following organizations may be involved:

- Architect/ Design Consultant
- Construction Management Firm
- General Contractor
- Sub Contractor 1 for finishing works
- Sub Contractor 2 for Mechanical, Electrical and Plumbing (MEP) works etc.

Each organization has its own working or non-working periods.

For example, see Table 1.

Table 1: Workdays for parties involved in a construction project

Calendar	Party	Work Period
1	General Contractor	7 Day Workweek (Mon – Sun)
2	Sub Contractor 1	7 Day Workweek (Mon – Sun)
3	Sub Contractor 2	6 Day Workweek (Mon – Sat)
4	Arch. & Design Consultant	5 Day Workweek (Mon – Fri)
5	Construction Mgmt Firm	7 Day Workweek (Mon – Sun)

- *Which calendar we will use for an activity?*

The calendar for the performing organization of that activity.

Note that Work Calendars can be different for:

- Organizations involved in the project
- Resources
- Activities

Note that each party may also have its designated holidays (non-work periods); for instance, national day, independence day, other company designated holidays, etc. Some of these non-work periods may be common among the various companies involved while some may belong to specific organizations only.

*Schedule of work performed by an organization will be based on the base calendar of that organization. More on this will be discussed later.*

Project base calendars provide the mechanism for converting work time to calendar time.