PROJECT TIME PLANNING

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COURSE TOPICS

Planning
  • Why we plan
  • The efficiencies of planning
  • What to consider in planning the construction project

Determining Activities
  • Scope of activities
  • Duration of activities
  • Sequence of activities
  • Relationship with other activities

Communicating the construction plan with the schedule

Creating bar charts

Understanding the critical path method of scheduling

Understanding computerized generation and application of the schedule

Updating the schedule
PROJECT PLANNING
WHAT IS PLANNING

The Development of a workable program of operations to accomplish established objectives when put into action.

Done before project starts

Planning for:

- Construction process
- Jobsite safety
- Jobsite layout
- Workforce
WHO NEEDS PLANNING

Owner
Designer
Contractor
  • Pre-tendering planning
  • Project Planning
BENEFITS OF PLANNING

Savings:
- Cost
- Time

Quality improvements
Avoided problems
Solved problems
PROBLEMS CAUSED BY NOT PLANNING

Additional costs
Project delays
Conflicts with other parties
Quality problems
“DAY-TO-DAY” PLANNING

Result in:

Wasted time
  • Labor cost
  • Longer construction time

Possible rework
  • Not anticipating future work
  • Cost and time impact

Inadequate project quality

Conflicts between subcontractors

Safety planning gets overlooked
PLANNING TEAM

“The whole is greater than the sum of its parts”
Define objectives and Scope of Work
Review plans, specs, and estimate
Visit jobsite
Identify potential problems/conflicts and critical issues
Determine general sequence (logic)
Draft rough diagram
Determine techniques & equipment
BRAINSTORMING
Identify long lead-time items
PRELIMINARY PLANNING

Preliminary planning is a quick overall picture of the project and the capacity of the unit to accomplish it.

Serves as a guide for detailed planning.

Includes preliminary material and equipment estimates, and procurement of critical items, identify work activities.
DETAILED PLANNING

Develops an accurate estimation of work activities, materials, man-hours, and equipment requirements needed from start to finish.

Detailed planning includes:

- Reviewing project specifications and drawings.
- Detailed estimates of resources, (i.e. equip. hours).
- Scheduling work activities.
- Procurement of materials.

Submitted in the form of a Gantt chart, PERT chart, Activity-on-the-Arrow logic diagram, or Activity-on-the-Node logic diagram.
STEPS OF PLANNING

1. Define Work Tasks
2. Choose Method of Construction
3. Estimating Activities Resources
4. Determine Activities Durations
5. Arrange Activities in Logical Sequence
6. Coding System
7. Planning technique
WORK BREAKDOWN STRUCTURE (WBS)

WBS - a task-oriented "family tree" of activities, which organizes, defines, and graphically displays the work to be accomplished.
WBS MUST

Establish an information structure for describing the project's scope;

Serve as an effective means of communication to integrate the objectives and activities of all the internal and external organizations involved in the project;

Represent the planning of the project, step by step;

Separate sequential and parallel activities assigned to different groups who will schedule, measure and control their own performance; and

Reflect the procurement strategy during the various stages of the project's life cycle.
WBS STEPS

Listing of project tasks to be performed
Starts at the major project view
Next the major phase levels are added
Then details for each phase are added

Tabular WBS

- 1.0 Project Level
- 1.1 Concept or Phase Level
- 1.2 Summary / Work Level
FOR EACH WORK PACKAGE (WP)

Brief description;
Activity list
Activity duration & relations
Activity resource allocation
Earliest start date;
Earliest end date;
Total person months effort;
Pre-requisite WPs or tasks;
Dependent WPs or tasks;
Who is responsible.
PROJECT TREE
There are many ways of breaking down the activities in a project, but the most usual is into:

- Work packages;
- Tasks;
- Deliverables;
- Milestones.
WBS CONSTRUCTION

Usually. . .

- Work packages are numbered wp1, wp2, . . . ;
- Tasks are numbered t1.1, t1.2, etc,
  - The first number is the number of the work package;
  - The second is a sequence number.
- Deliverables are numbered d1.1, d1.2, etc
- Milestones are numbered M1, M2 etc.
WORK PACKAGES

A Work Package describes the work to be performed by a specific organizational unit, and serves as a vehicle for monitoring and reporting on progress, cost and schedule.

All work packages fall into one of three different categories:

- **Discrete Tasks** which have a specific end result or objective. These normally cover 60 to 75% of the total project work.
- **Apportioned-effort Tasks** which can be directly related and to discrete tasks. Examples include quality control or inspection.
- **Level-of-effort Tasks** which have performance standards rather than specific end results. These consist mainly of the overhead accounts, e.g., management, administration, coordination, etc.
A WORK-PACKAGE

Independent of other activities;
But may depend on other activities;
May include multiple concurrent activities;
Typically allocated to a single team.
TO BE EFFECTIVE, WORK PACKAGES

Rule 1: A work package must represent a unit of work at a level where work is performed.

Rule 2: It must be clearly distinguishable from all other work packages.

Rule 3: It should have scheduled start and completion dates.

Rule 4: It should have a budget.

Rule 5: Its size and duration should be limited to relatively short spans of time.
TO BE EFFECTIVE, WORK PACKAGES

Rule 6: It must integrate with other work packages and schedules.

Rule 7: It must represent a level at which actual costs can be collected or assigned.

Rule 8: On small projects: a work package should at least be large enough to constitute a scope of work that could be competitively bid and contracted for by itself.

Rule 9: On large, multi-million dollar projects design work packages should not be less than, say, 300 man-hours and two months in duration.
AN ACTIVITY...  

is a specific task  
has a beginning and an end  
has a duration  
usually consumes resources  
  • Material, labor, equipment, subcontractors  
is assignable (someone does it)  
is measurable in quantity or time  
has a relationship to other activities  
has delivery associated with it
ACTIVITY SIZE/SCOPE

Relates to:

• Size of project
• Crew size
• Number of crews
• Details required by contract documents
• Amount of jobsite control of the schedule
## COMPARISON OF ACTIVITY DETAIL

<table>
<thead>
<tr>
<th>GENERAL</th>
<th>DETAILED</th>
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<tbody>
<tr>
<td>• Form and pour footings</td>
<td>• Lay out footings</td>
</tr>
<tr>
<td></td>
<td>• Form footings</td>
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<tr>
<td></td>
<td>• Install footing rebar</td>
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<tr>
<td></td>
<td>• Pour footings</td>
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<tr>
<td></td>
<td>• Strip footings</td>
</tr>
</tbody>
</table>
ACTIVITY LISTS

An activities (task) list is a complete listing of all required work activities that must be performed from start to finish.

An activity list can be brief, or as detailed as need be. The guiding factor to how much detail that is required is related to size and complexity of the project.
ACTIVITY LISTS

An activity list must be developed mentally and on paper to determine actual activities and their interrelationships to each other.

The most difficult step is your ability to think logically, and make a mental picture of the project in your mind.

Brainstorming is needed with the assistance of the Chief's, and the Project Officer.
METHODS OF ESTIMATING DURATION

Estimate time for specific crew
Production output from estimating manuals
Subcontractor input
Supplier input
DURATION OF ACTIVITIES

The amount of time between the start and the finish of the activity

Usually in “days” in construction schedules

“Day” = working day

Need to make accurate estimate of time

Account for minor delays in activity duration

\[
\text{Activity Duration} = \frac{\text{Work Quantity}}{\text{No. of Crews} \times \text{Production Rate}}
\]
ESTIMATING ACTIVITY DURATIONS EXAMPLE:

Need to Excavate 1000 m³
One crew consist of (1 excavator, 2 trucks)
One crew production = 100 m³/day
Two crews are available

So.....

\[
Excavation \ Duration = \frac{1000}{2 \times 100} = 5 \text{ working days}
\]
SEQUENCING ACTIVITIES

After you have developed your rough activity list in no specific order, you must now put the activities into a "logical" sequence to be performed.

Continuous flow of work shows “How are we going to build the project?”
LOGIC DIAGRAM RULES

There are five types of activities associated with the development of a finished activities list.

- Starting activities → beginning activity
- Preceding activities → previous activity
- Concurring activities → occurring at the same time
- Succeeding activities → following activity
- Lagging activities → slow or lingering activities

Keeping these activities in mind will help you in your logical thinking to develop the activity list on paper.
ACTIVITY RELATIONSHIPS

Finish-to-Start (FS)

- Activity must be complete before next activity starts
- Example: Footings before foundation wall
ACTIVITY RELATIONSHIPS

Start-to-Start (SS)

- Start of the second activity is related to the start of the first activity
- Could be a separation of time, or lag between the starts
ACTIVITY RELATIONSHIPS

Finish-to-Finish (FF)

- The finish of the first activity must be complete before the finish of another activity
- Lags can be used

Diagram:
- Install Plumbing Sleeves
- Form & Pour Foundation Wall
**ACTIVITY RELATIONSHIPS**

Start-to-Finish (SF)

- One activity cannot finish until the other activity is started
- Not used as frequently as the other relationships
**EXAMPLE: LIST ACTIVITIES**

<table>
<thead>
<tr>
<th>No.</th>
<th>Activity</th>
<th>Description</th>
<th>Duration</th>
<th>Relationship</th>
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<td>2</td>
<td>Cleaning</td>
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<td>5</td>
<td>PC Footing Formwork</td>
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**EXAMPLE:**
**DESCRIBE ACTIVITIES**

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<td>Cleaning</td>
<td>Cleaning site, bring site to elevation</td>
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<td>Layout building axis</td>
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<td>PC Footing Formwork</td>
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EXAMPLE: SKETCHING ACTIVITY SEQUENCE
PLANNING DIAGRAMS

The planning diagram graphically shows the interrelationship between project activities.

It provides a visual blueprint of the work activities that must be performed during construction.

There are few types of diagrams that can be created.

Each type of diagram serves a specific purpose.
PLANNING TECHNIQUES

Bar Chart

Network models
  • Activity on arrow
  • Activity on node

Line of balance and time location
BAR CHART (GANTT CHART)

Graphical representation employed since early 1900’s
Used primarily for small projects.
Bars show an activities durations regardless of its dependency on other activities.
Easy to construct, and are brief in format.
Horizontal axis = timescale
Vertical scale lists activities
BAR CHART (GANTT CHART)

Advantages

• Easy to read
• Good communication tool
• Easy to update

Disadvantages

• Does not show detailed sequence of activities.
• Does not show "critical activities".
• Does not show the exact progress of the project.
Suppose that a site preparation and concrete slab foundation construction project consists of nine different activities:

A. Site clearing,
B. Removal of trees,
C. General excavation,
D. Grading general area,
E. Excavation for utility trenches,
F. Placing formwork and reinforcement for concrete,
G. Installing sewer lines,
H. Installing other utilities,
I. Pouring concrete.
### Relations Between Activities

<table>
<thead>
<tr>
<th>Activity</th>
<th>Description</th>
<th>Predecessors</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Site clearing (of brush and minor debris)</td>
<td>----</td>
</tr>
<tr>
<td>B</td>
<td>Removal of trees</td>
<td>----</td>
</tr>
<tr>
<td>C</td>
<td>General excavation</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>Grading general area</td>
<td>A</td>
</tr>
<tr>
<td>E</td>
<td>Excavation for utility trenches</td>
<td>B,C</td>
</tr>
<tr>
<td>F</td>
<td>Placing formwork and reinforcement for concrete</td>
<td>B,C</td>
</tr>
<tr>
<td>G</td>
<td>Installing sewer lines</td>
<td>D,E</td>
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<td>H</td>
<td>Installing other utilities</td>
<td>D,E</td>
</tr>
<tr>
<td>I</td>
<td>Pouring concrete</td>
<td>F,G</td>
</tr>
</tbody>
</table>

![Graph showing the sequence and duration of activities]
NETWORK DIAGRAMS

Displays project graphically

Presents activities as they relate to each other

- Logic ties
- Predecessors and successors

Computer software enables greater use of network diagrams
ACTIVITY-ON-ARROW

✓ Original CPM developed by duPont in late 1950’s
✓ Shows relationship and activity on arrows connected by nodes
✓ The nodes represent milestones of possible beginning and starting times
✓ Every activity is presented by an arrow that starts at a node and ends at a node
✓ Starting activities start at one node
✓ An end node represents the completion of all activities.
✓ May have to use Dummy Activity
ACTIVITY-ON-ARROW

Excavation → P.C. Footing → R.C. Footing → Filling

Insulation
Activity C depend on Activities A and B
Activity D depend on Activity B
EXAMPLE: ACTIVITIES ON ARROW

<table>
<thead>
<tr>
<th>Activity</th>
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<tbody>
<tr>
<td>A</td>
<td>----</td>
</tr>
<tr>
<td>B</td>
<td>----</td>
</tr>
<tr>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>D</td>
<td>A</td>
</tr>
<tr>
<td>E</td>
<td>B,C</td>
</tr>
<tr>
<td>F</td>
<td>B,C</td>
</tr>
<tr>
<td>G</td>
<td>D,E</td>
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<tr>
<td>H</td>
<td>D,E</td>
</tr>
<tr>
<td>I</td>
<td>E,G</td>
</tr>
</tbody>
</table>
ACTIVITY-ON-NODE

Originally developed as PERT by the U.S. Navy also during late 1950’s

AON format is "activity" oriented.

Every activity is presented by a rectangle

Arrows show relationship only
ACTIVITY-ON-NODE

✓ Start from left to right
✓ Dependency between activities are presented by lines
✓ Every activity in the network has to be preceded by another activity or the project start
✓ Every activity must be followed by a successor or the project finish
✓ Every path must be continuous form the project start to the project end (no gaps are allowed)
ADVANTAGES OF ACTIVITY-ON-NODE

✓ Provides an outline for long-range planning.
✓ Shows activity interrelationships.
✓ Focuses attention on critical activities.
✓ Allows to make timely decisions.
✓ Allows to manage resources more effectively.
ACTIVITY-ON-NODE

Excavation → P.C. Footing → R.C. Footing → Filling

Insulation
PROJECT SCHEDULING
PROJECT SCHEDULING

Critical Path Method (CPM):

- A network analysis technique used to predict project duration by analyzing which sequence of activities (which path) has the least amount of scheduling flexibility (the least amount of float).

Program Evaluation & Review Technique (PERT)

- An event-oriented network analysis technique used to estimate project duration when there is a high degree of uncertainty with the individual activity duration estimates.
- PERT applies the critical path method to a weighted average duration estimate.
CPM SCHEDULING STEPS

Calculate Each activity duration
Calculate total project duration
Calculate starting and ending time of each activity
Define critical activities
Conduct time reduction if needed
Define the needed recourses (resource management)
Define the calendar dates
PERT TIME CALCULATION:

Beta distribution

- $t_e = (t_o + 4t_m + t_p) / 6$
  - Optimistic time ($t_o$)
  - Most likely time ($t_m$)
  - Pessimistic time ($t_p$)
  - Estimated time ($t_e$)

![Diagram showing Beta distribution with optimistic, most likely, and pessimistic time points and PERT weighted average calculation.](image)
ACTIVITY TYPES

Task Activity
Start & finish milestones
Start & finish flags
Independent
Meeting
Hammock
CRITICAL PATH METHOD (CPM)

D = Duration
ES = Early Start
EF = Early Finish
LS = Late Start
LF = Late Finish
ES ≤ LS, EF ≤ LF

<table>
<thead>
<tr>
<th>Activity Code</th>
<th>Activity Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ES = Early Start</td>
<td>EF = Early Finish</td>
</tr>
<tr>
<td>LS = Late Start</td>
<td>LF = Late Finish</td>
</tr>
</tbody>
</table>
EARLY/LATE EVENT TIMES

Early Start (ES):
- The earliest time a activity can logically start.

Early Finish (EF):
- The earliest an activity can finish without delaying follow on activities. (ES + Duration)

Late Finish (LF):
- The latest an activity can finish without delaying the entire project.

Late Start (LS):
- The latest time an activity can start without delaying the entire project. (LF - Duration)
FORWARD / BACKWARD PASS

After all duration's have been computed, you are now able to calculate each activities Early and Late event times.

Forward Pass
- Completed left to right
- Calculates ES, EF, and project duration
- EF = ES + D
  - Where 2 or more chains converge on a single activity, the larger value controls

Backward Pass
- Completed right to left or end back to the beginning
- Calculates LF, LS
- LS = LF - D
  - Where 2 or more chains converge on a single activity, the smallest value governs
FLOAT “SLACK TIME”

Difference between early and late times

Allows activity to begin later than ES and not prolong the project

Two types of float:

• Total float
• Free float
TOTAL FLOAT

Is the maximum amount of delay which can be assigned to any activity without delaying the entire project. The total float (TF) for any activity is calculated as:

$$TF = LS - ES = LF - EF$$

Each of these "floats" indicates an amount of flexibility associated with an activity.

In all cases, total float equals or exceeds free float.

Any activity on a critical path has all floats equal to zero.
FREE FLOAT

Free Float (FF) is the amount of delay which can be assigned to any one activity without delaying subsequent activities.

For activity X that depend on Activity Y in a Finish to start relation, The free float, associated with activity Y is:

$$FF_Y = ES_X - EF_Y$$

For activity X that depend on Activity Y in a Start to start relation, The free float, associated with activity Y is:

$$FF_Y = ES_X - ES_Y$$
CRITICAL PATH & CRITICAL ACTIVITIES

After completing the event times, you can determine the "critical path" of the project and all of the "critical activities" by simple observation using the following guidelines:

- The ES for an activity is the same as its LS.
- The EF for an activity is the same as its LF.

Continuous chain of activities with longest durations

Determines project duration
**EXAMPLE 1**

Activities A and B are the first activities in the project.

Activity C starts 1 day after the finish of B and 3 days after the start of A.

Activity D depends on the finish of activity B.

Activity E depends on the finish of C and starts 4 days after the start of C.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Depend on</th>
<th>Relation</th>
<th>Lag</th>
<th>Duration</th>
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<td>-</td>
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<td>-</td>
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<td>-</td>
<td>6</td>
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<td>C</td>
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<td>-</td>
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<td>E</td>
<td>C</td>
<td>SS</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>
EXAMPLE 1
EXAMPLE 1

A

B

C

D

E

START

FINISH

0 6

6 6 12

0 8

0 8 8

9 14

9 5 14

8 14

18 6 24

0 0

6/6

3

4

1

10/10

24

24

24 0 24

0/0

0/0

9

9

14

14

24

10 24

0/0
EXAMPLE 2
EXAMPLE 2
Program Evaluation and Review Technique [PERT]
Program Evaluation and Review Technique (PERT) is appropriate for scheduling and controlling research and development type projects, or others comprised of activities whose actual duration times are subject to considerable chance of variation (random variation).

Critical Path Method (CPM) has used a single time estimate for each network activity. This is because, in construction, each activity is "deterministic" in the sense that similar or identical work has been performed many times before.

- The single time estimate of the activity completely ignores the chance of variability associated with the conduct of the project activities.

Sources of variation include weather, equipment failure, personnel or materials problems, or uncertainties in the method or procedures to be used in carrying out the activity.
The advantage of the PERT statistical approach is that it offers a method of dealing with this chance variation, making it possible to allow for it in the scheduling calculations, and finally using it as a basis for computing the probability (index) that the project, or key milestones in the project, will be completed on or before their scheduled dates.

Probability has already been defined as a way of measuring uncertainty.

PERT uses three time estimates for each activity: (1) an optimistic or minimum time, (2) a most likely or modal time, and (3) a pessimistic or maximum time. This is a "probabilistic" approach that lends itself to activities for which there is no historical record of experience.
THREE ACTIVITY DURATIONS

Three activity durations/times should be estimated for each activity:

1. **Optimistic Performance Time** ($a/T_o$): the time which would be bettered only one time in twenty if the activity could be performed repeatedly under the same essential conditions. The activity is executed under very favorable conditions. The probability of being completed within this duration is about 0.05. (optimistic time = short time)

2. **Pessimistic Performance Time** ($b/T_p$): the time which would be exceeded only one time in twenty if the activity could be performed repeatedly under the same essential conditions. The activity is performed under very unfavorable conditions. The probability of its occurrence is about 0.05. (pessimistic time = long time)

3. **Most Likely Time** ($m/T_m$): the modal value of the distribution, or the value which is likely to occur more often than any other value. Usually closest to the actual durations. Very high probability.
THREE ACTIVITY DURATIONS

- The mean, expected, activity duration ($t_e$)
  - The three time estimates are made for the activity concerned and an expected time, $t_e$, is computed. $t_e$ is then used as the best available time approximation for the activity in question.

\[ \text{Mean} = t_e = \frac{(a + 4m + b)}{6} \]

- Where, $a =$ optimistic time, $m =$ most likely time, and $b =$ pessimistic time.
1. If an activity is performed a large number of times and record of the actual durations is maintained, a plot of frequencies of such durations will give the beta-curve (an unsymmetrical curve).

\[
\begin{align*}
(t \leq a) \quad p(a) &= 0.05 = p(4) \\
(t \geq b) \quad p(b) &= 0.05 = p(7) \\
(t \leq m) \quad p(m) &= \text{High} = p(6)
\end{align*}
\]
2. Because the vertical line drawn at the most likely time \((m = 6.0)\) does not divide the area under the curve into two equal parts, the probability of completing this activity in six time units is not 0.5.

3. \[ t_e = \frac{a + 4m + b}{6} = \frac{4 + 4*6 + 7}{6} = 5.8. \]

4. \( t_e \) divides the area under the beta curve into two equal parts.

5. The probability that the activity will be finished in the \( t_e \) of 5.8 units is 0.5.

6. \( t_e \) represents a points at which there is a 50-50 chance that the actual activity completion will be earlier or later than \( t_e \).
A measure of central tendency locates the point about which the distribution is centered.
A measure of variability (dispersion) indicates the spread or dispersion in the distribution.
In PERT computations, the arithmetic mean will use as a measure of central tendency, and the standard deviation as a measure of variability.
Measures of Central Tendency and dispersion

- Measure of central tendency = arithmetic mean = \( \bar{t} \)
  \[ \bar{t} = \frac{(t_1 + t_2 + \ldots + t_n)}{n} \]
  where, \( n \) = number of observations

- Measure of variability = standard deviation = \( \sigma \) (\( s_t \))
  \[ \sigma = \left\{ \frac{[(t_1 - \bar{t})^2 + (t_2 - \bar{t})^2 + \ldots + (t_n - \bar{t})^2]}{n} \right\}^{1/2} \]
  where, \( n \) = number of observations

Standard deviation = root-mean-square deviation; it is the square root of the mean of the squares of the deviations of the individual observations from their average.
In PERT computations, \( \bar{t} \) and \( \sigma (t) \) will be denoted by \( t_e \) and \( (V_t)^{1/2} \), respectively; \( \bar{t} \) approaches \( t_e \) and \( s_t \) approaches \( (V_t)^{1/2} \), as the size of the sample, \( n \), approaches infinity.

- Measure of central tendency = arithmetic mean = \( \bar{t} = t_e \)
  
  \[ \text{Mean} = t_e = (a + 4m + b)/6 \]

- Measure of variability = standard deviation = \( \sigma (t) = s_t = (V_t)^{1/2} \)
  
  \[ (V_t)^{1/2} = \sigma (t_e) = (b - a)/3.2 \]

- The square of standard deviation, called the variance;
  \( \sigma^2 (t) = s_t^2 = \text{variance of } t = (V_t). \)
  
  \[ V_t = \sigma^2 (t_e) = [(b - a)/3.2]^2 \]

  - The variance describes the uncertainty associated with the time-estimating process.
  - If the variance is large, there is a great uncertainty about when the activity will be completed. If the variance is small, so is the uncertainty.
Project Duration

- When $t_e$ has been determined for each activity, project duration ($T_E$) and float can be determined from $t_e$ by forward and backward passes as in a CPM network.

- Since the probability is 0.5 that each activity will finish at its expected time $t_e$, there is a probability of 0.5 for the entire project being finished at time $T_E$.

- The expected project duration times do not follow a beta curve but follow a normal distribution curve; therefore the expected project durations may be assumed normally distributed.
Central Limit Theorem

- Central Limit Theorem is the basis of PERT probability computations.
- If the number of critical activities \((m)\) is large, say four or more, then the distribution of \(T\) is approximately normal with mean \(\mu\) and variance \(\sigma^2\) given by:
  \[
  T = t_{e1} + t_{e2} + \ldots + t_{em}
  \]
  \[
  \sigma^2 = \sigma_{t1}^2 + \sigma_{t2}^2 + \ldots + \sigma_{tm}^2
  \]
- The distributions of the sum of activity times will be NORMAL regardless of the shape of the distribution of actual activity performance times.
Schedule (Time) Performance

- If the random variable \( t \) is “normally” distributed, that is, the distribution has a characteristic symmetrical bell shape.
- \( te \)'s follow a normal distributions, and not beta-distributions as activity durations te’s do.

The total area under such a curve is made to be exactly one, so that the area under the curve between any two values of \( t \) is directly the probability that the random variable \( t \) will fall in this interval.
Selected Areas under the Normal Distribution Curve

- 68.26% of area
- 95.45% of area
- 99.973% of area

Normal distribution

Mean = $t_0$

Standard deviation = $(\sigma)^{1/2}$
1. The mean, expected, activity duration ($t_e$)

$$\text{Mean} = t_e = \frac{(a + 4m + b)}{6}$$

where

- $a =$ Optimistic duration
- $m =$ most likely duration
- $b =$ pessimistic duration

2. We can use time estimates, $a$ and $b$, to estimate the standard deviation ($V_t^{1/2}$) or the variance, $V_t$, as follow:

$$V_t^{1/2} = \sigma (t_e) = \frac{(b - a)}{3.2} \quad (5\%-95\% \text{ Assumption})$$

$$V_t = \sigma^2 (t_e) = \left[\frac{(b - a)}{3.2}\right]^2$$

$V_t = \sigma^2 (t_e) =$ Uncertainty about the activity durations, where:

- If $(b - a)$ is a large figure, greater uncertainty,
- If $(b - a)$ is small amount, less uncertainty.
PERT Computations

1. Calculate expected activity duration ($t_e$)

$$t_e = \frac{(a + 4m + b)}{6}$$

where

- $a$ = Optimistic duration
- $m$ = Most likely duration
- $b$ = Pessimistic duration

2. Calculate standard deviation of an activity ($\nu$)

$$\nu^{1/2} = \sigma (t_e) = \frac{(b - a)}{3.2}$$

3. Calculate variance of an activity ($\nu$)

$$\nu = \sigma^2 (t_e) = \left[\frac{(b - a)}{3.2}\right]^2$$

4. Do CPM analysis, using ‘$t_e$’ as activity times.
PERT Computations

5. Identify critical activities with activities times "$t^*$"

6. Calculate project time ($T_e$)
   \[ T_e = \sum t^* \]

7. Calculate project variance ($V_T$) = $\sigma^2 (T_e)$
   \[ V_T = \sigma^2 (T_e) = \sum \sigma^2 (t^*) \]
   - For multiple critical paths, consider the highest total of variances.

8. Calculate project standard deviation ($V_T^{1/2} = \sigma (T_e)$)
   \[ \sigma (T_e) = (V_T^{1/2}) \quad \text{or} \quad \sigma (T_e) = \sqrt{V_T} \]
The Central Limit Theorem enables one to assume that the shape of the distribution of $T_e$ is approximately normal. This information is summarized in the following figure, where the distribution is shown to “touch down” on the abscissa at three standard deviations on either side of the mean, i.e., at $T_e \pm 3\sigma (T_e)$.

The probability that the project will be finished in time $T_e$ is 0.5 or $p(T_e) = 0.5$.

The total area under such a curve is made to be exactly one, so that the area under the curve between any two values of $T$ is directly the probability that the random variable $T$ will fall in this interval.
PERT Computations

Normal distribution

Mean = $T_e$

Standard deviation = $(\nu)^{1/2} = \sigma (T_e)$

- $68.26\%$ of area
- $95.45\%$ of area
- $99.973\%$ of area

$T_e - (\nu)^{1/2}$

$T_e + (\nu)^{1/2}$

$T_e - 2(\nu)^{1/2}$

$T_e + 2(\nu)^{1/2}$

$T_e - 3(\nu)^{1/2}$

$T_e + 3(\nu)^{1/2}$

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The following steps should be considered when computing the probability of occurrence of an event, on or before a scheduled time.

1. Make the usual forward and backward pass computations based on a single-time estimate, \( t_e \), for each activity.

2. Suppose one wishes to compute the probability of meeting a specified scheduled time for event \( X \). Then determine the “longest path” from the initial event to the event \( X \).

3. Compute the variance for event \( X \), \( (V_T) \), by summing the variances for the activities listed in Step 2. \( V_T = \text{sum of values of } [(b - a) / 3.2]^2 \), for each activity on the “longest path” leading to event \( X \).
4. Compute $Z$ using the following equation and look up the corresponding probability in the normal curve table. In order for this table to apply to any normal curve, it is based on the deviation of the scheduled date in question, $T_s$, from the mean of the distribution, $T_e$, in units of standard deviations, $\sigma (T_e) = (V_T)^{1/2}$. Calling this value $Z$, one obtains

$$P\{T \leq T_s\} = P\{Z \leq z = \frac{T_s - E(T)}{\sqrt{V_T}}\}$$

- A value of $Z = 1.25$ (e.g.) indicates that the scheduled time, $T_s$, is 1.25 standard deviations greater than the expected time, $T_e$.
- It is essential that the correct sign is placed on the $Z$. 
Example

The basic information for a small research and development project is listed in the table below. Use PERT technique to answer the following questions:

<table>
<thead>
<tr>
<th>Activity</th>
<th>Depends on</th>
<th>Time in Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>a</td>
</tr>
<tr>
<td>A</td>
<td>—</td>
<td>2</td>
</tr>
<tr>
<td>B</td>
<td>—</td>
<td>4</td>
</tr>
<tr>
<td>C</td>
<td>—</td>
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</tr>
<tr>
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<td>G</td>
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<td>C</td>
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<td>I</td>
<td>D &amp; E</td>
<td>3</td>
</tr>
<tr>
<td>J</td>
<td>F &amp; G</td>
<td>2</td>
</tr>
</tbody>
</table>
Example

1. Find the expected project duration $T_e$, and project standard deviation $\sigma_T$.
2. What is the probability of completing the work in 15 weeks?
3. What is the probability of completing the work at 15 weeks?
4. What is the probability of not meeting a deadline of 15 weeks?
5. What is the due date that will have a 75% chance of meeting (round of to the closet digit)?
6. What is the probability that Activity I can start by week 8th? OR, what is the probability of finishing Activity D by 8 weeks?
7. What is the probability of completing the project between 10 weeks and 12 weeks?
8. What is the probability of not completing the project between 10 weeks and 12 weeks?
### Example

<table>
<thead>
<tr>
<th>Activity</th>
<th>Depends on</th>
<th>Time in Weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>a</td>
<td>m</td>
</tr>
<tr>
<td>A</td>
<td>2</td>
<td>3</td>
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<td>I</td>
<td>D &amp; E</td>
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</tr>
<tr>
<td>J</td>
<td>F &amp; G</td>
<td>2</td>
</tr>
</tbody>
</table>
Example
1. Project time = $T_e = \sum t_e$
   $T_e = 3 + 4 + 6 = 13$ weeks (the probability that the project will be finished in 13 weeks is 0.5 or $p(T \leq 13) = 0.5$.

Project variance $V_T = \sigma^2 (T_e) = \sum \sigma^2 (t_e)$
   
   $V_T = 0.39 + 0.39 + 3.52 = 4.3$

   $\sigma (T_e) = (V_T)^{1/2} \sigma_t = \sqrt{4.3} = 2.074$

2. $P(T < 15) = P(Z < z = 15 - 13 / 2.074) = P(Z < 0.9643) = 83.25%$

3. $P(T = 15)$, $\Rightarrow Z = z = 0.9643 = 83.25%$

4. $P(T > 15)$, $\Rightarrow 1 - P(T \leq 15) = 0.1675 = 16.75%$
5. \( P(T) = 75\% \Rightarrow Z_{75\%} = 0.675 = \Rightarrow T_{75\%} = 0.675 \times 2.074 + 13 \)

\[ .: \ z = 14.4 \text{ weeks} \]

6. \( T_D = 7 \text{ weeks}, \ V_D = 0.39 + 0.39 = 0.78, \sigma_D = \sqrt{0.78} = 0.8832 \)

\( P(T \leq 8) = P(Z \leq z = 8 - 7 / 0.8832) = P(Z \leq 1.132) = 87.1\% \)

7. \( P(10 < T < 12), \Rightarrow P(T < 12) - P(T < 10) = \)

\[ P(Z < z = 12 - 13 / 2.074) - P(Z < z = 10 - 13 / 2.074) \]

\[ P(Z < -0.482) - P(Z < -1.447) = 0.3156 - 0.074 = 24.16\% \]

8. \( P(10 > T > 12) = 1 - P(10 < T < 12) = 1 - 0.2416 = 0.7584 = 75.84\% \)
Example

6.78 8.85 10.93
15.08 17.15 19.2

$T_E \pm \sigma T_E$

$T_E \pm 2\sigma T_E$

$T_E \pm 3\sigma T_E$
Entry is area $1 - \alpha$ under the standard normal curve from $-\infty$ to $z(1 - \alpha)$.
### Cumulative Probabilities of the Standard Normal Distribution

<table>
<thead>
<tr>
<th>$z$</th>
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<th>0.01</th>
<th>0.02</th>
<th>0.03</th>
<th>0.04</th>
<th>0.05</th>
<th>0.06</th>
<th>0.07</th>
<th>0.08</th>
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<tbody>
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</table>
EXAMPLE 3

You have following data for a certain project:

Calculate the expected time of this project, as well as the different activities' times.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Depend on</th>
<th>Optimistic time (week)</th>
<th>Most like time (week)</th>
<th>Pessimistic time (week)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>E, F</td>
<td>1</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>B</td>
<td>D</td>
<td>3</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>C</td>
<td>D</td>
<td>2</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>D</td>
<td>-</td>
<td>1</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>E</td>
<td>C, B</td>
<td>2</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>F</td>
<td>B</td>
<td>4</td>
<td>6</td>
<td>14</td>
</tr>
</tbody>
</table>
EXAMPLE 3
**EXAMPLE 3**

Expected time = \((\text{Optimistic time} + 4 \times \text{Most like time} + \text{Pessimistic time}) / 6\)

Expected Project time = 20 weeks

<table>
<thead>
<tr>
<th>Activity</th>
<th>Optimistic time (week)</th>
<th>Most like time (week)</th>
<th>Pessimistic time (week)</th>
<th>Expected Time (week)</th>
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<tbody>
<tr>
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<td>4</td>
<td>7</td>
<td>4</td>
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<tr>
<td>B</td>
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<td>4</td>
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<td>5</td>
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<td>3</td>
<td>11</td>
<td>4</td>
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<tr>
<td>E</td>
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<td>F</td>
<td>4</td>
<td>6</td>
<td>14</td>
<td>7</td>
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</table>
PROJECT
TIME
REDUCTION
CRASHING

The first trial of the scheduling of a project will result in excessive project duration.

Sometimes, there is a need to reduce project time to meet contractual requirements.

Critical path shows the activities that must be examined to reduce the project duration.

Reducing activity time is usually called “crashing”

The aim of crashing is to reduce the time with minimum cost.
WHEN TIME REDUCTION IS NEEDED?

To meet a contractual project completion date.
To avoid liquidated damages
To avoid adverse weather
To move labor and equipment to another location
To cover a delay by the end of the project
HOW TO REDUCE PROJECT TIME WITHOUT INCREASING THE COST

Restudy critical activities
Accomplish critical activities in parallel
Subdivision of critical activities
Subcontracting

If those items did not work, we may have to reduce project time by increasing project cost
TIME-COST RELATIONSHIPS

The direct cost of an activity vary with time

**Normal cost:**
- is the least direct cost required to complete that activity and it is the cost estimated to finish the work during bidding stage.

**Normal duration:**
- is the activity duration determined during scheduling stage.

**Crashing time:**
- is the minimum time to which an activity can be reduced.

**Crashing cost:**
- is the corresponding direct cost for the crashing time.

**Cost slope:**
- is the increase in activity direct cost per day.
ACTIVITY DIRECT COST

Cost Slope = \((\text{Crash cost} - \text{Normal cost})/ (\text{normal time} - \text{crash time})\)
PROJECT INDIRECT COST

Indirect cost is the cost incurred in support of the site work but it can not be associated with any particular physical portion of the job.

The indirect cost is directly related to project time.
If the duration of a specific activity is reduced or crashed:

- Direct expenses increases
- Overall project duration decreases
- Indirect cost is reduced
PROCEDURE FOR CRASHING

Least Cost Method has been developed to reduce project duration with the least cost.

It is based on the investigation of the network to indicate which activities can be reduced at least cost when reducing project duration.

We start crashing with activities that have lowest cost slope.
**EXAMPLE 1**

<table>
<thead>
<tr>
<th>Activity</th>
<th>Normal Time</th>
<th>Crash Time</th>
<th>Crash Cost</th>
<th>Normal Cost</th>
<th>Cost Slope</th>
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<tbody>
<tr>
<td>A</td>
<td>6</td>
<td>2</td>
<td>10,000</td>
<td>6,000</td>
<td>1000</td>
</tr>
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<td>B</td>
<td>5</td>
<td>3</td>
<td>20,000</td>
<td>16,000</td>
<td>2000</td>
</tr>
<tr>
<td>C</td>
<td>8</td>
<td>5</td>
<td>8,000</td>
<td>3,500</td>
<td>1500</td>
</tr>
<tr>
<td>D</td>
<td>6</td>
<td>5</td>
<td>10,000</td>
<td>6000</td>
<td>4000</td>
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</table>
**EXAMPLE 1**

The diagram illustrates a network flow problem with nodes labeled as **A**, **B**, **C**, and **D** along with their respective values. The network starts from **Start** and ends at **Finish**.

<table>
<thead>
<tr>
<th>Node</th>
<th>Value</th>
<th>Next Node</th>
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<tbody>
<tr>
<td>A</td>
<td>0/6</td>
<td>B</td>
</tr>
<tr>
<td>B</td>
<td>6/0</td>
<td>A</td>
</tr>
<tr>
<td>C</td>
<td>6/14</td>
<td>D</td>
</tr>
<tr>
<td>D</td>
<td>6/12</td>
<td>C</td>
</tr>
<tr>
<td>Start</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Finish</td>
<td>0</td>
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The values indicate the cost or duration of moving from one node to another.
Original plan

A = 1000

B = 2000

C = 1500

D = 4000

1 day from A = 1000

A = 1000

B = 2000

C = 1500

D = 4000

1 2 3 4 5 6 7 8 9 10 11 12 13 14
2 days from C = 1500/day

A = 1000

B = 2000

D = 4000

C = 1500/day

2 days from A&B = 3000/day

A = 1000

B = 2000

D = 4000

C = 1500
1 days from C&D = 5500/day

<table>
<thead>
<tr>
<th>Step</th>
<th>Activity</th>
<th>Cost/day</th>
<th>Days</th>
<th>Cost</th>
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<td>A</td>
<td>1000</td>
<td>1</td>
<td>1000</td>
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<tr>
<td>2</td>
<td>C</td>
<td>1500</td>
<td>2</td>
<td>3000</td>
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<tr>
<td>3</td>
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<td>C&amp;D</td>
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Total cost to crash project duration to 8 = 15,500
### EXAMPLE 2

<table>
<thead>
<tr>
<th>Activity</th>
<th>Normal Time (weeks)</th>
<th>Crash Time (weeks)</th>
<th>Normal Cost (L.E.)</th>
<th>Crash Cost</th>
<th>Cost Slope</th>
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<td>5</td>
<td>3</td>
<td>1000</td>
<td>1200</td>
<td>100</td>
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<tr>
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<td>3250</td>
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The indirect cost is L.E. 500 per week.
Project total cost is L.E. 45,000
Calculate the optimal cost for this work and the corresponding duration.
<table>
<thead>
<tr>
<th>Activity</th>
<th>Crashed days</th>
<th>Increased Direct cost</th>
<th>Project duration</th>
<th>Decreased indirect cost</th>
<th>Variance in project cost</th>
<th>Project cost</th>
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PROJECT CONTROL

Control = Measure + Comparison + Analysis + Action

Control:
• Time
• Cost
• Quality

Milestones:
• Progress milestones
• Contractual milestones
TIME MANAGEMENT SYSTEM

No plan can ever be perfect.

No planner can anticipate every future job conditions.

Problems arise every day that could not have been foreseen such as:

- Adverse weather
- Material delivery delay
- Labor disputes
- Equipment breakdowns
- Job accidents
- Change orders

Thus, after construction starts, the original schedule must be evaluated.
TIME MANAGEMENT CYCLE

1. Establish operational schedule
2. Measure and report progress
3. Compare actual achievement with that planned
4. Determine effect on completion date
5. Plan and implement corrective action
6. Update operation schedule
At regular intervals, the stage of project advancement is observed and reported.

At each cutoff date, note is made of:

- Completed activities
- Canceled (deleted) activities
- New (added) activities
- New relations between activities (new dependencies)
  - Logic dependency
  - Resource dependency
- The changes in activities durations
- New stopping periods
- Time of conducting the update
To make periodic measurement of progress in the field, consider network activities.

The advancement of an activity in the progress can be expressed in different ways.

Commonly used methods are:

1. Estimated number of working days required to complete the activity
2. Estimated percentage completion of the activity in terms of time
3. Quantities of work units put into place
PROGRESS MEASUREMENT

Working days to complete = d \times (1 - P/100)
Working days to complete = d \times (1 - W/T)

Where:

- d = total activity duration in working days
- P = estimated percentage of completion
- W = number of work units put into place
- T = total number of work units associated with the activity

The above equation assumes a straight linear equation between time and work accomplishment.
On receiving the progress measurement from the field, management must compare the information with the latest schedule.

The comparison could be in form of tables or bar chart.

The bar chart is an excellent tool for recording progress information.

However, it is not a proper tool for evaluating the overall time status of the project.

Also, bar chart consumes a lot of time and money if it is done manually.
PROGRESS ANALYSIS

The analysis of job progress is done to determine the effect of this latest information on the project completion date. The analysis is concerned with determining the present length of critical path.

If OK, check the possibility of the formation of a new critical path.

To do this, check the LF of non critical activities with their actual finish times.

There is a need to identify the reasons of activity delays.
CORRECTIVE ACTIONS

After analyzing the progress report, a decision must be made to what corrective action is needed.

Small delays will not usually require any particular corrective action. Using contingency allowances will provide the needed time.

Corrective actions are needed in the following cases:
1. Activities fall behind their late start and late finish dates
2. Substantial resource delays
3. Duration of future activities are unrealistic
4. Logic changes of future work
EXAMPLE 1

Given

• a network and information about the status of each activity at specific update time

Solution:

• First step is to solve the network and define activities times
• Develop a new network based on the update data
EXAMPLE 1

A
B
C
D
E
F
G

8
9
6
5
7
9
8

5
8

EXAMPLE 1

At the end of the 10th day the following information were available:

- Activities A and B were completed
- Activities D did not start yet
- 50% of Activity C was completed
- Activity E was Omitted
- Activity F duration is expected to be 8 days

Required:

Draw the updated (reduced) network and comment on project progress
SOLUTION EXAMPLE 1

Diagram of a solution example with nodes A, B, C, D, E, F, and G, connecting with edges and numbers indicating the sequence and duration of activities from start to finish.
SOLUTION EXAMPLE 1

Remember:

The updated network starts at the update date

We do not draw completed activities in the updated network

Activity start at zero means that it start at the beginning of the first working day

Activity end at 8th day: means it ends at the end of the 8th working day

Any activity that was not mentioned, it is assumed that it is following the original scheduling information