Precedence Networks

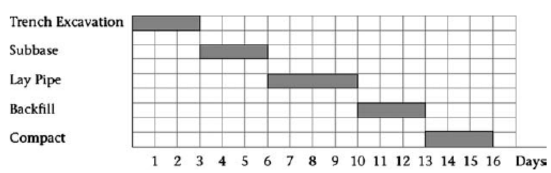
Chapter 2

Precedence networks

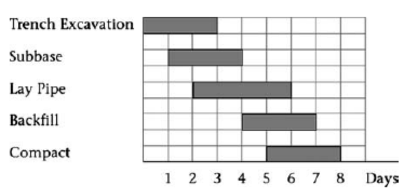
- Precedence networks are node networks that allow for the use of four types of relationships
  - FS, SS, FF, SF
- Example: A simple project of laying 1,000 m (linear meter) of a utility pipe having only five consecutive activities .
  - dig a trench
  - provide a 15 cm -thick gravel sub-base (bedding)
  - lay the pipe
  - Backfill and
  - compact

FS and overlapping representation

- IF the traditional FS relationship is applied:

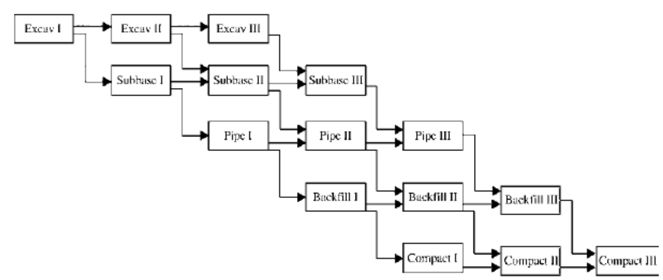


- IF activities are overlapping (practical)



The stair-type relationship

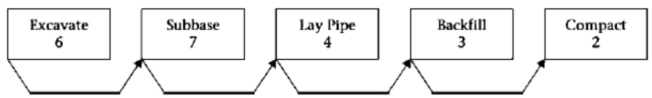
- each activity is divided into two or more parts



Increase in the number of activities and the confusing similarity of their titles

Precedence diagram method (PDM)

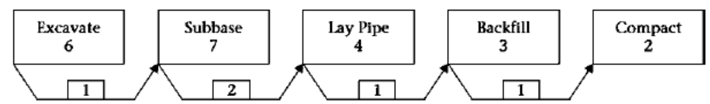
- Alternatively PD using SS relationships



- Theoretically, all five activities can start simultaneously,
- Project can be completed in 7 days

PDM with lags

- We can add lags:
- For example:
  - if excavate starts on day 0
  - Sub-base can start 1 day later,
  - Lay Pipe can start 2 days later
  - Backfill can start on day 4 , and
  - Compact can start on day 5

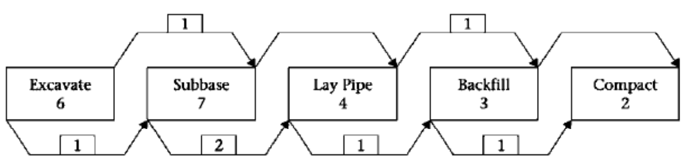


Problem : Compact (day 7), however, Subbase, has not finished. Unacceptable!

Solution : Increase the lags on SS Relationship or add FF relationships

PDM with lags

- FF ensures that no successor can finish before its predecessor.
- FF and SS with lags



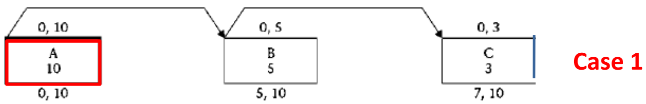
Note: Subbase cannot finish till 1 day after Excavate has finished, and Backfill cannot finish till 1 day after Lay Pipe has finished.

CPM calculations for PD

- The CPM calculations for precedence diagrams differ from those for standard arrow or node diagrams.
- Assumption about activities makes a substantial difference in the calculation method
  - continuous or
  - interruptible
- Assume Interruptible Activities (it can be paused and then resumed)

CPM calculations for PD

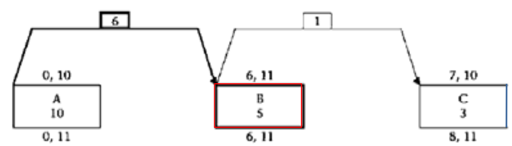
- **Simple example**
- Three activities with SS and no lags



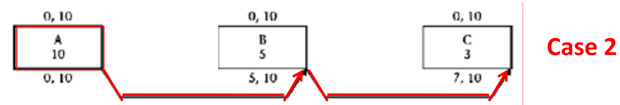
- Theoretically, all three activities can start at the same time.
- The project finishes when A finishes (longest duration)
- A is critical
- The float for B is 10-5 = 5 and for C is 10 – 3 =7 (diff in activity duration b/n A and B and C)

CPM calculations for PD

- Add lags (SS with lags)
- Only B is critical. Activity C may finish early, on day 10, which is 1 day before activity B (may or may not be a **problem**)

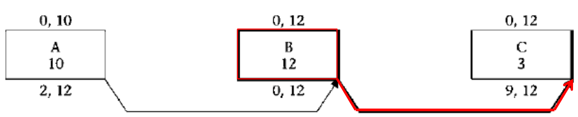


- Try to tie the ends of the activities with FF rather than the SS relationships (A and the finish of B and C become **critical**)



CPM calculations for PD

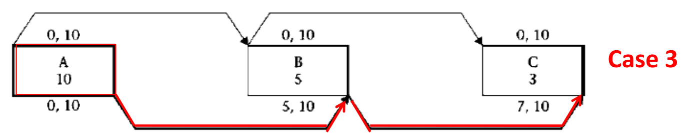
- No restriction is put on their start other than the start of the project.
- Suppose activity B has 12 days duration (criticality change)



- Activity B becomes critical. The end of activity C is still critical, since it is tied to the end of B.
- B : the driving activity (It has no control over the completion of the predecessor, but it has control over the finish of activity C

CPM calculations for PD

- If we tie both the start and the end of the activities



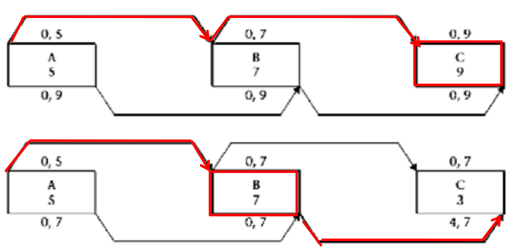
- Two activities tied with two relationships, in most cases, one of these two relationships governs (i.e. becomes driving) **FF**

Comparing cases 1 &3 : activities B and C not allowed to finish before day 10, the finish date for activity A. Calculated dates differ

Comparing cases 2 &3 no differences as far as dates are concerned. However, a logic difference exists. The **FF** relationship controls.

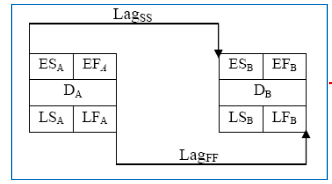
CPM calculations for PD

- This control can change with a change in duration



- Duration of any activity may be longer than EF - ES or LF - LS.
- Interruptible activity (i.e., started, stopped, and then resumed)

CPM calculations for PD



Forward Pass

$ES_B = ES_A + Lag_{SS}$

$EF_B = ES_B + D_B$
$EF_B = EF_A + Lag_{FF}$
} Whichever is longer

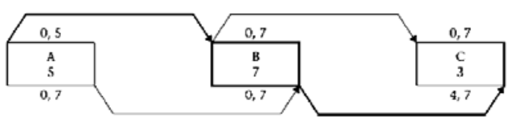
Backward Pass

$LF_A = LF_B - Lag_{FF}$

$LS_A = LF_A - D_A$
$LS_A = LS_B - Lag_{SS}$
} Whichever is smaller

Example

- Consider the previous example with SS and FF



- In the forward pass:
- **Activity A**
  - activity A starts the project
  - ES = 0; EF = 0 + 5 (duration) = 5

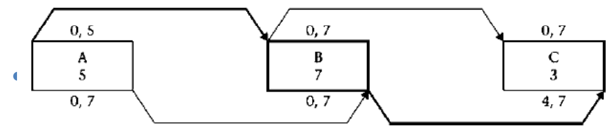
CPM calculation

- **Activity B**
  - The SS relationship (with no lag) means B can start just after A has start
  - ES = 0. However, its EF is controlled by the later of the following two:
    - EF = ES + D = 0 + 7 = 7 or
    - EF(B) = EF(A) + Lag (if any) = 5 + 0 = 5
  - Thus, EF = 7

CPM calculation

- **Activity C**
  - Its start is controlled by the start of activity B, so its ES = 0.
  - ES = 0. However, its EF is controlled by the later of the following:
    - EF = ES + D = 0 + 3 = 3 or
    - EF (C) = EF (B) + Lag (if any) = 7 + 0 = 7
  - Thus, EF = 7

CPM calculation



- In the backward pass:
- **Activity C**
  - start at the end of activity C with its finish no earlier than day 7
  - LF = 7; LS = LF - D = 7 - 3 = 4

CPM calculation

- **Activity B**
  - Activity B must finish no later than the LF of C
  - LF (B) = LF (C) - Lag = 7 - 0 = 7
  - Its LS is controlled by the earlier of the following:
    - LS = LF - D = 7 - 7 = 0 or
    - LS (B) = LS(C) – lag (if any) = 4 - 0 = 4
    - Thus, LS = 0

CPM calculation

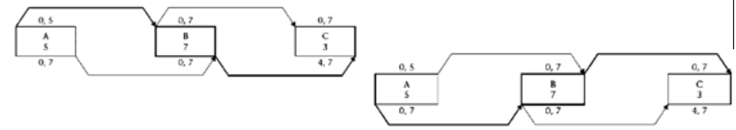
- **Activity A**
  - Activity A must finish no later than the LF of B
  - LF (A) = LF (B) - Lag = 7 - 0 = 7
  - Its LS is controlled by the earlier of the following:
    - LS = LF - D = 7 - 5= 2 or
    - LS (A) = LS(B) – lag (if any) = 0 - 0 = 0
    - Thus, LS = 0

CPM calculation

- Note the durations may not be equal to
  - EF - ES (example Activity C)
  - LF – LS (example Activity A)
- Total float is always calculated by using this simple equation:
  - TF = LF - D - ES
- Free float (FF) is calculated the same way

Arrows and Dangling Activity

- The position of the relationship arrows (i.e., from top or bottom of the same side) is arbitrary.

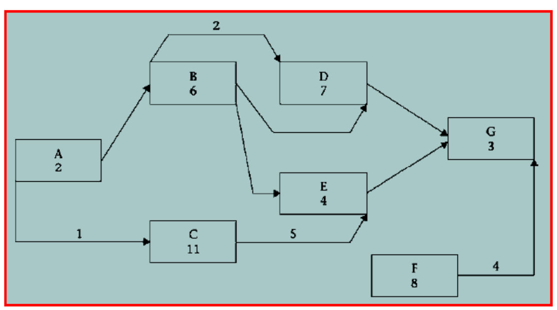


- We may have dangling activities in precedence diagrams. Dangling activities are tied from one end only (may have either no predecessors or no successors). Example:

Nothing controls the end of the Clear & Grub activity (other than the end of the project). LF = end of project

Example

- Perform the CPM calculations for the network shown in Figure



Relationship	Type
A-C	SS
B-D	SS FF
C-E	FF
F-G	FF

All the other relationships are FS

Solution

- **Forward Pass**
  1. Start the project at activity A
     ES = 0, EF = 0 + 2 = 2
  2. Activity B can start as soon as activity A is finished
     ES = 2, EF = 2 + 6 = 8
  3. Activity C can start 1 day after A has started
     ES = 1, EF = 1 + 11 = 12
  4. Activity D can start 2 days after activity B has started
     ES =2 + 2 = 4
     Use the later of EF = 4 + 7 = 11 and the EF (for B) = 8
     Thus, EF = 11

Solution

5. Activity E can start as soon as B is finished.
   ES = 8, Use the later of EF = 8 + 4 = 12 and EF (for C) + 5-day lag = 12 + 5 = 17. Thus, EF = 17
6. Activity F has no restriction for its start (dangling activity).
   ES = 0, EF = 0 + 8 = 8
7. Activity G can start after both D and E are finished. ES (for G) = 17 (the later of 11 and 17). Use the later of EF = 17 + 3 = 20 and EF (for F) + 4-day lag = 8 + 4 = 12. We choose EF = 20.
8. The calculated early finish date for the project is day 20 (project duration is 20 days).

Solution

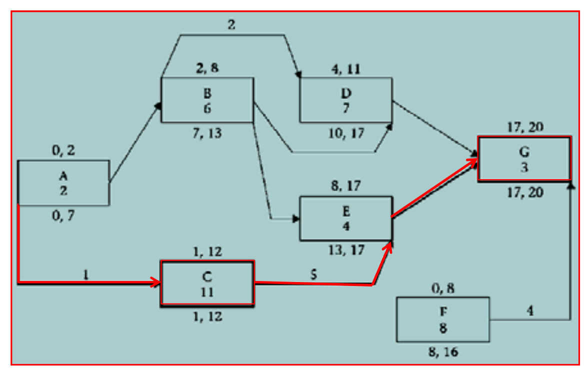
- **Backward Pass**
  1. Start at activity G
     LF = 20, LS = 20 - 3 = 17
  2. Activity F must finish 4 days prior to the finish of activity G
     LF = 20 – 4 = 16; LS = 16 - 8 = 8
  3. Activity E must finish before G can start.
     LF = 17, LS = 17 - 4 = 13
  4. Activity D must finish before G can start.
     LF = 17, LS = 17 - 7 = 10
  5. Activity C must finish 5 days before the finish of E.
     LF = 17 - 5 = 12, LS = 12 - 11 = 1

Solution

6. Activity B must finish before D has finished, on day 17, and before E has started, on day 13
   LF = 13 (the earlier). Use the earlier of
   LS = LF –D = 13 - 6 = 7 and
   2 days before the LS for D (i.e., 8)
   Thus, LS = 7
7. Activity A must finish before B can start.
   LF = 7. Use the earlier of
   LS = 7 - 2 = 5 and LS (for C) - 1-day lag = 1 - 1 = 0.
   Thus, LS = 0

Solution

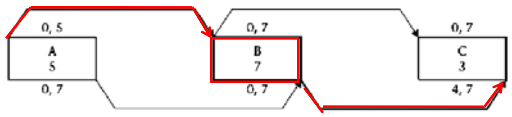
- The critical path is the start of A, all of C, the end of E, and all of G



The total float equals 5, 5, 6, 5, and 8 for A, B, D, E, and F, respectively.

Restricted Floats

- Duration of an activity not equal to EF - ES or LF – LS (activity A and C)



- Activity A must start on day 0; otherwise, the start of activity B, which is critical, will be delayed. (its start can not be delayed)
- The only restriction on the finish of activity A is that it should not delay the LF of activity B, which is day 7.

Restricted Floats

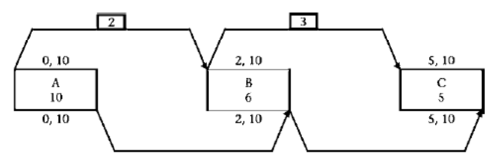
- This leaves activity A with 7 days, but it has only 5 days' duration.
- Therefore, activity A has 2 days of **start- restricted float**
- The crew for activity A has only two options:
  - 1. Start the activity on day 0, work nonstop, and finish early on day 5.
  - 2. Start the activity on day 0, finish a certain portion, take a break, and finish the activity by day 7.
  - Can not start on day 2 and finish on day 7

Restricted float

- Activity C has 4 days of float in its start. However, no matter when it starts, it must finish on day 7; not before, not after.
- Activity C has 4 days of **finish-restricted float**.
- The work crew has the following two options:
  - 1. Start the activity on day 0, finish a certain portion, take a break (or breaks) of 1 to 4 days, and return and finish the activity by day 7.
  - 2. Delay the start of the activity till day 4, work nonstop, and finish on day 7.
  - Not possible to start early and finish early on day 3

Restricted Floats

- Another example:



- Activity B must start on day 2 and must finish on day 10.
- It has only 6 days' duration but must fill an 8-day time interval.
- We call the difference (8-6=2) start-finish-restricted float or **double-restricted float**.

Continuous activities

- CPM calculations are similar with one exception:
- We must satisfy the following equation:
  - Dur = EF - ES = LF - LS
- Restricted float are not allowed
- Project completion durations might be longer
- The solution of the previous example becomes: