Week 6

Project Scheduling (1)

457.307 Construction Planning and Management

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Project Scheduling (PMBOK Chapter 6)

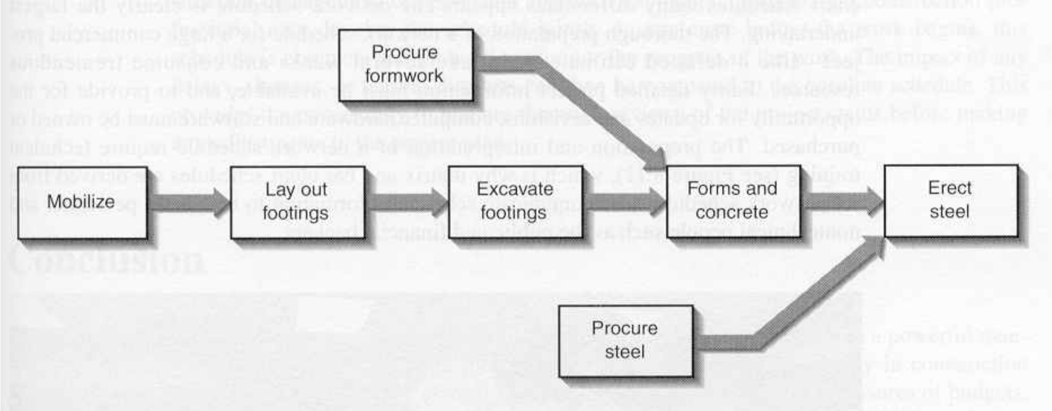
- **Project Time Management**
  - Includes the process required to ensure timely completion of the project
- **Major Processes**
  1. Activity definition
  2. Activity sequencing
  3. Activity duration estimation
  4. Schedule development
  5. Schedule control

Project Scheduling – Activity Definition

- **WBS being the basis for development of the final activity list**
- **Tools and Techniques**
  - Decomposition
    - Involves subdividing project elements into smaller, more manageable components in order to provide better management control
  - Templates
    - An activity list, or a portion of an activity list from a previous project, is often usable as a template for a new project
    - Resource skills, required hours of effort, risk identification, expected deliverables, etc.

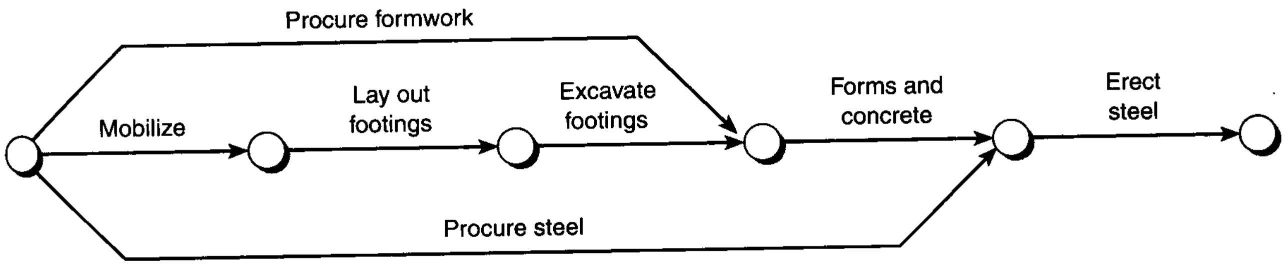
Project Scheduling – Activity Sequencing

- **Identifying interactivity dependencies**
  - Precedence Diagramming Method (PDM) called Activity-On-Node (AON)



(b) Activity on node notation

  - Arrow Diagramming Method (ADM) called Activity-On-Arrow (AOA), "old school" not much used as more



(a) Activity on arrow notation

Project Scheduling – Activity Sequencing

- **Precedence Notation**
  - Activities or operations are placed on nodes
  - Arrows defines relationships between activities
    - Finish to Start
    - Start to Start
    - Finish to Finish
    - Start to Finish
  - Apply "lags" provide ability to overlap activities, allowing the scheduler to model more accurately the project's operation

Project Scheduling – Duration Estimate

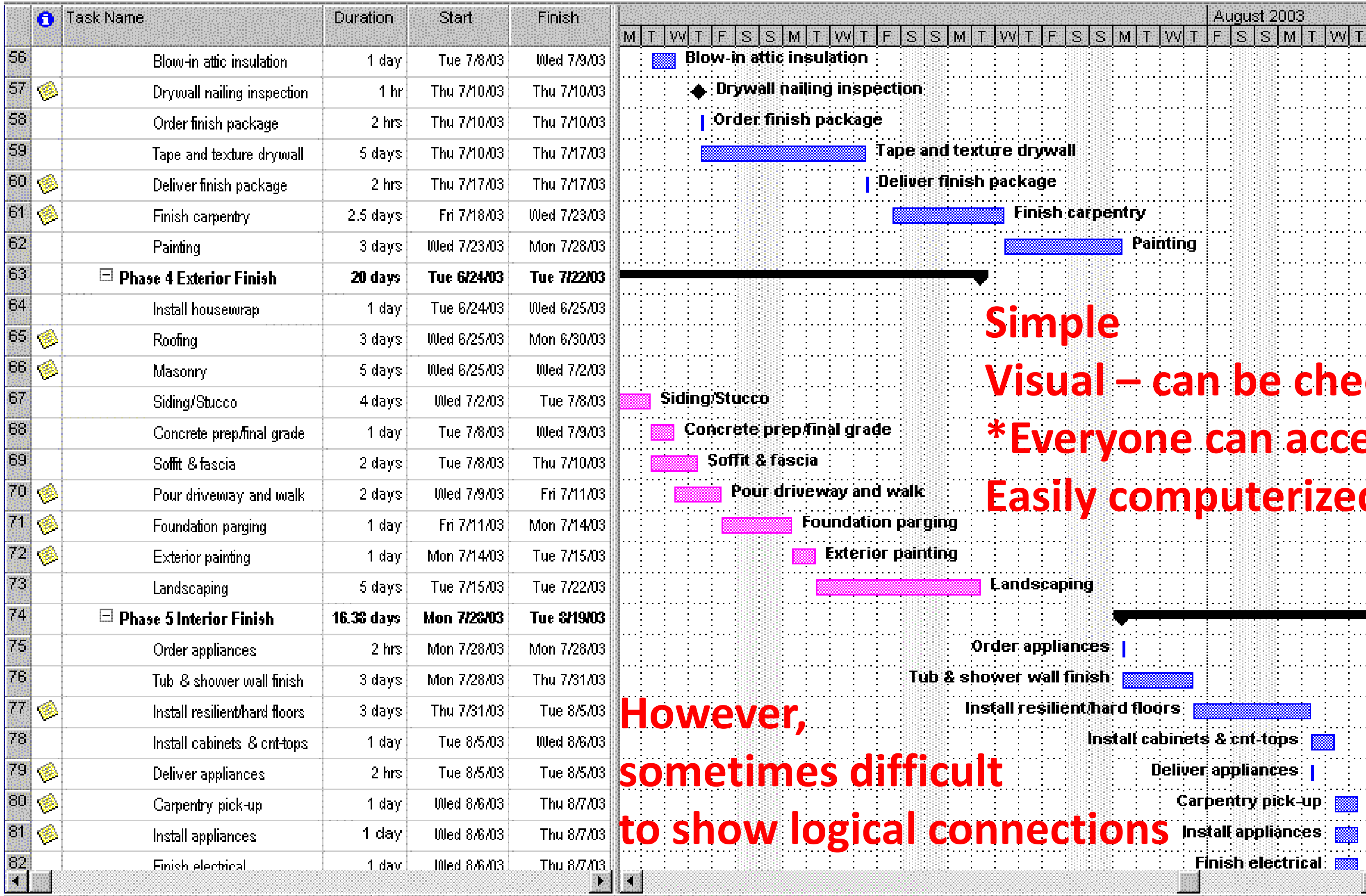
- **Estimating the number of work periods which will be needed to complete individual activities**
- **Tools and Techniques**
  - Expert judgment: historical information may be used
  - Analogous estimating: called top-down estimation, means using the actual duration of a previous, similar activity
  - Simulation: involves calculating multiple durations with different sets of assumptions

Project Scheduling – Duration Estimate

- **Duration of an activity varies according to the activity type**
  - Production
    - Consult subcontractors
    - Calculate based on quantity and productivity
    - Job conditions, new construction vs. renovation, crew size, work schedule, weather, project calendar, resource calendar
  - Procurement
    - Consult suppliers
    - Review contract documents
  - Administrative
    - Consult agencies
    - Past projects

Project Scheduling – Schedule Development

- Bar (Gantt) chart



		Task Name	Duration	Start	Finish
56		Blow-in attic insulation	1 day	Tue 7/8/03	Wed 7/9/03
57		Drywall nailing inspection	1 hr	Thu 7/10/03	Thu 7/10/03
58		Order finish package	2 hrs	Thu 7/10/03	Thu 7/10/03
59		Tape and texture drywall	5 days	Thu 7/10/03	Thu 7/17/03
60		Deliver finish package	2 hrs	Thu 7/17/03	Thu 7/17/03
61		Finish carpentry	2.5 days	Fri 7/18/03	Wed 7/23/03
62		Painting	3 days	Wed 7/23/03	Mon 7/28/03
63		**Phase 4 Exterior Finish**	**20 days**	**Tue 6/24/03**	**Tue 7/22/03**
64		Install housewrap	1 day	Tue 6/24/03	Wed 6/25/03
65		Roofing	3 days	Wed 6/25/03	Mon 6/30/03
66		Masonry	5 days	Wed 6/25/03	Wed 7/2/03
67		Siding/Stucco	4 days	Wed 7/2/03	Tue 7/8/03
68		Concrete prep/final grade	1 day	Tue 7/8/03	Wed 7/9/03
69		Soffit & fascia	2 days	Tue 7/8/03	Thu 7/10/03
70		Pour driveway and walk	2 days	Wed 7/9/03	Fri 7/11/03
71		Foundation parging	1 day	Fri 7/11/03	Mon 7/14/03
72		Exterior painting	1 day	Mon 7/14/03	Tue 7/15/03
73		Landscaping	5 days	Tue 7/15/03	Tue 7/22/03
74		**Phase 5 Interior Finish**	**16.38 days**	**Mon 7/28/03**	**Tue 8/19/03**
75		Order appliances	2 hrs	Mon 7/28/03	Mon 7/28/03
76		Tub & shower wall finish	3 days	Mon 7/28/03	Thu 7/31/03
77		Install resilient/hard floors	3 days	Thu 7/31/03	Tue 8/5/03
78		Install cabinets & cnt-tops	1 day	Tue 8/5/03	Wed 8/6/03
79		Deliver appliances	2 hrs	Tue 8/5/03	Tue 8/5/03
80		Carpentry pick-up	1 day	Wed 8/6/03	Thu 8/7/03
81		Install appliances	1 day	Wed 8/6/03	Thu 8/7/03
82		Finish electrical	1 day	Wed 8/6/03	Thu 8/7/03

Simple

Visual – can be checked

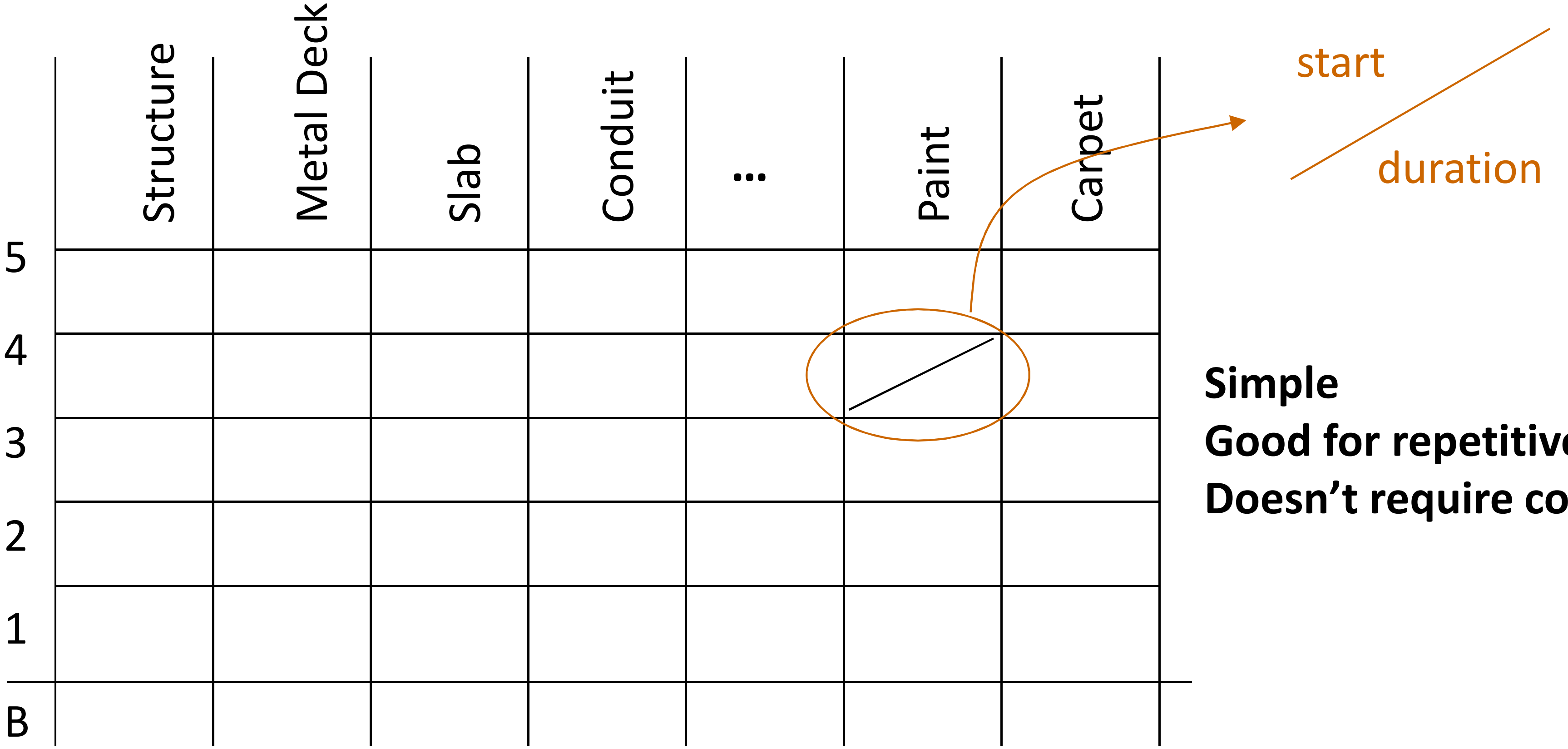
*Everyone can access

Easily computerized

However, sometimes difficult to show logical connections

Project Scheduling – Schedule Development

- ## Matrix Schedules

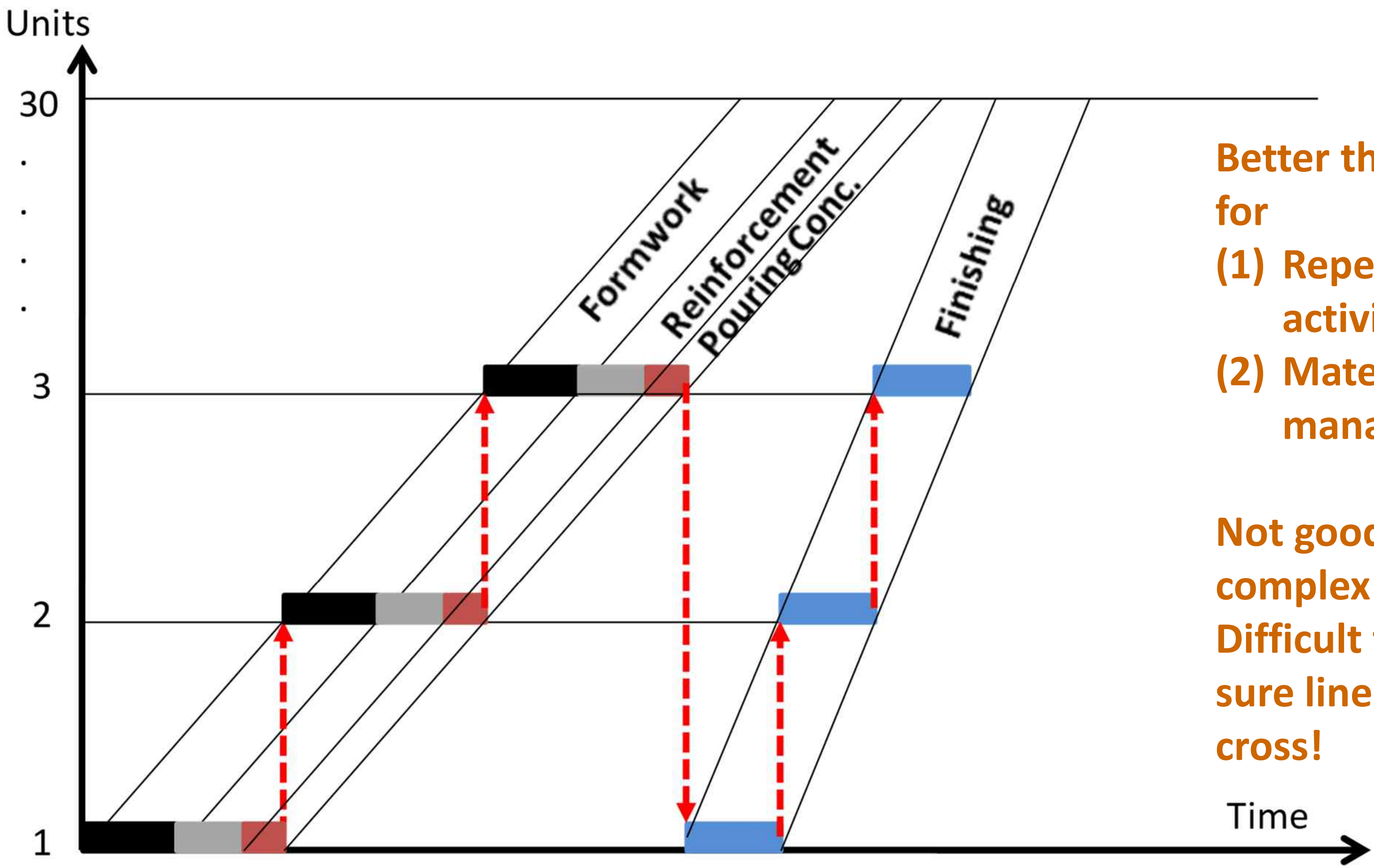


Simple
Good for repetitive work
Doesn't require computer

Hard to use for complex work
Typically useful only for part of project
Difficult to define relationships

Project Scheduling – Schedule Development

- ## Line of Balance



Better than matrix for
(1) Repetitive activities and
(2) Material management

Not good for complex project: Difficult to make sure lines don't cross!

Project Scheduling – Schedule Development

- **Terminology**
  - Early Start (ES): earliest possible time an activity can start based on the logic and durations identified in the network
  - Early Finish (EF): earliest possible time an activity can finish based on the logic and durations identified in the network
    - **EF = ES + Activity Duration**
  - Late Finish (LF): latest possible time an activity can finish based on the logic and durations identified in the network without extending the completion date of the project
  - Late Start (LS): latest possible time an activity can start based on the logic and durations identified in the network without extending the completion date of the project
    - **LS = LF – Activity Duration**

Project Scheduling – Schedule Development

- **Terminology**
  - Float: additional time an activity can use beyond its normal duration and not extend the completion date of the project
    - Total Float (TF): maximum time an activity can be delayed without delaying the project completion
    - Free Float (FF): maximum time an activity can be delayed without delaying the start of any succeeding activity
  - Critical Path: path from start to finish with no float. Therefore, it is the minimum time to complete the project and highly impacts on the entire project schedule.

    Delay in Critical Path = Project Delay!

Project Scheduling – Schedule Development

- **Development Methods**
  - Critical Path Method (CPM): calculates a single, deterministic early and late start and finish date for each activity based on specified, sequential network logic and using duration estimate
  - Program Evaluation and Review Technique (PERT): uses sequential network logic and a weighted average duration estimate to calculate project duration

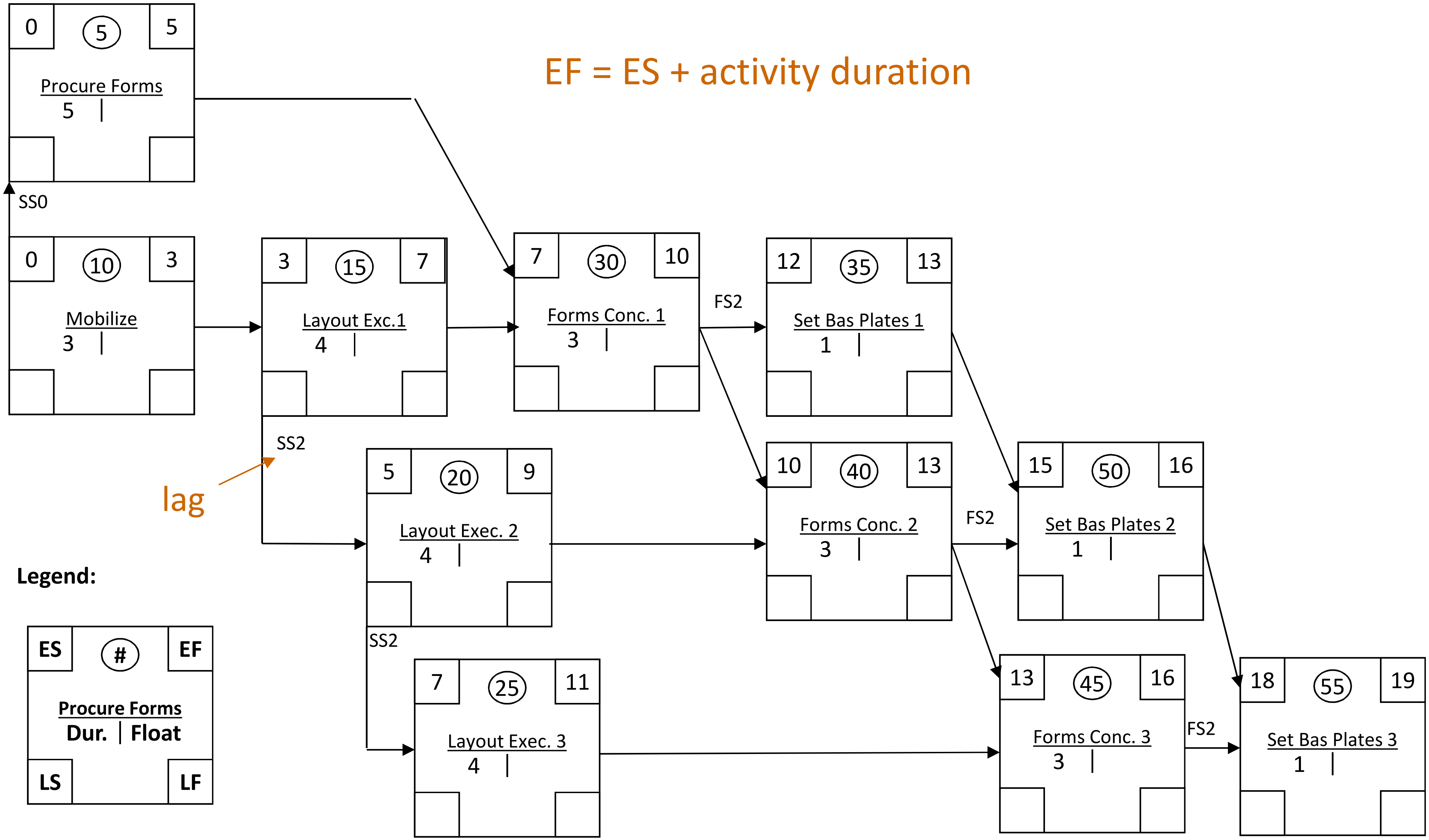
Project Scheduling – Schedule Development

- **Network Forward Path Calculations – AON**
  - AON (precedence notation) – Finish to Start Links
    - Activities without predecessors
      - Early Start = 0
      - Early Finish = Early Start + Activity Duration
    - Activities with predecessors
      - Early Start = maximum Early Finish among predecessors
      - Early Finish = Early Start + Activity Duration

IMPORTANT: Pay attention when working with different link types or when there are lags

Mobilize and procurement of forms → Concrete layout setting → Place concrete in forms → Finalize base concrete plate

Forward Path Calculation

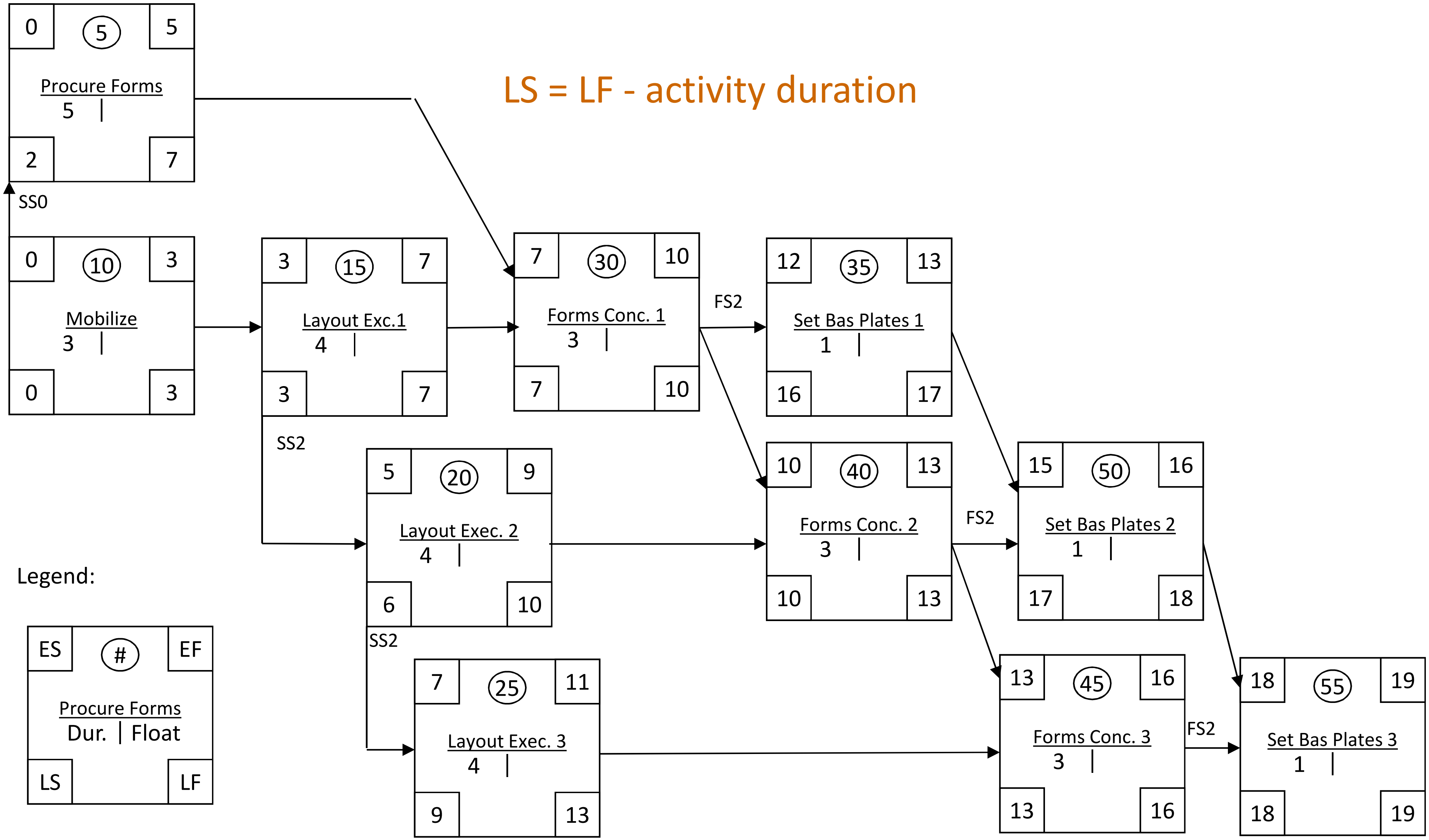


Project Scheduling – Schedule Development

- **Network Backward Path Calculations – AON**
  - AON (precedence notation) – Finish to Start Links
    - Activities without successors
      - Late Finish = Early Finish (or project duration)
      - Late Start = Late Finish – Activity Duration
    - Activities with successors
      - Late Finish = minimum Late Start among successors
      - Late Start = Late Finish – Activity Duration

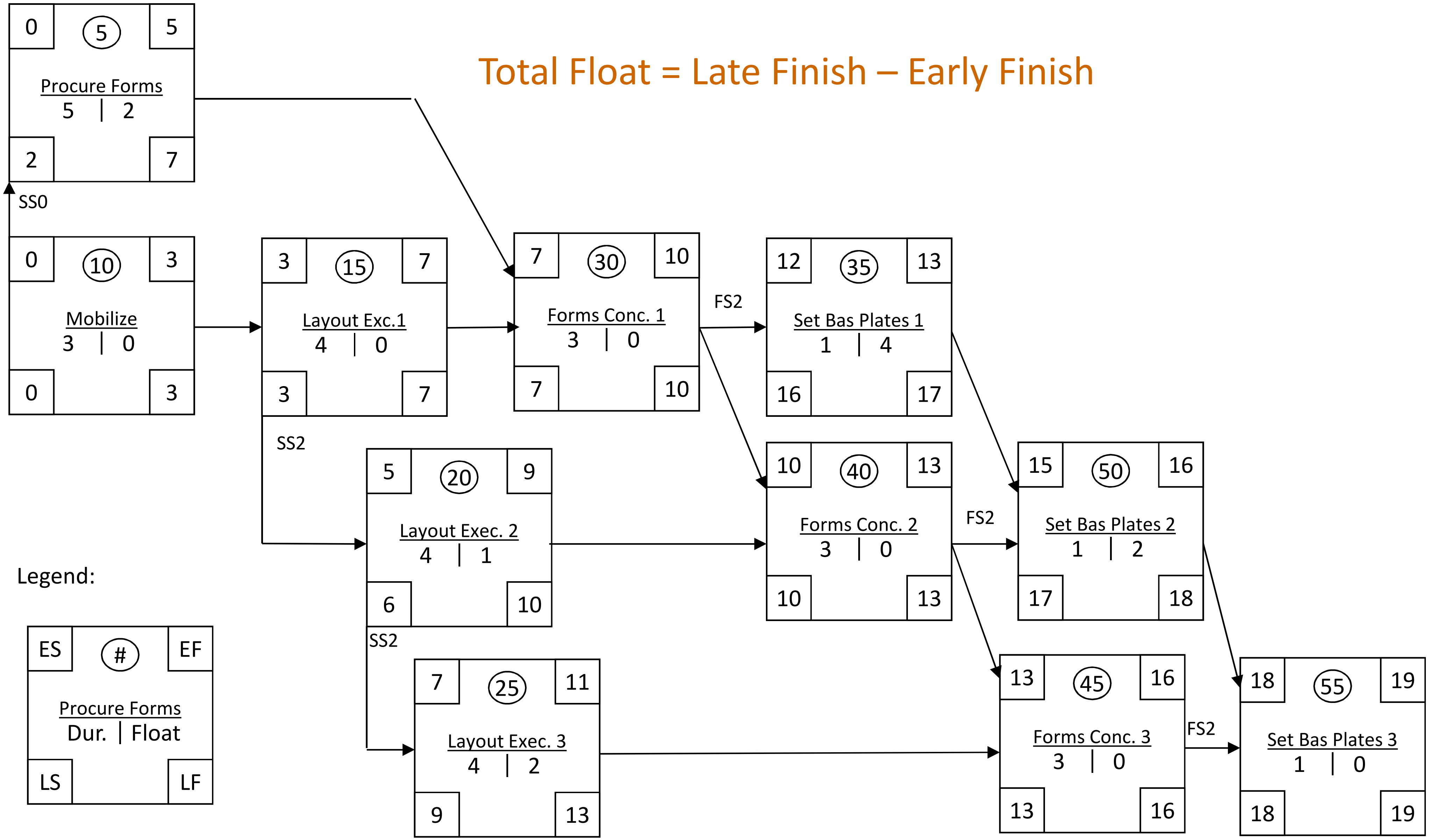
Backward Path Calculation

LS = LF - activity duration

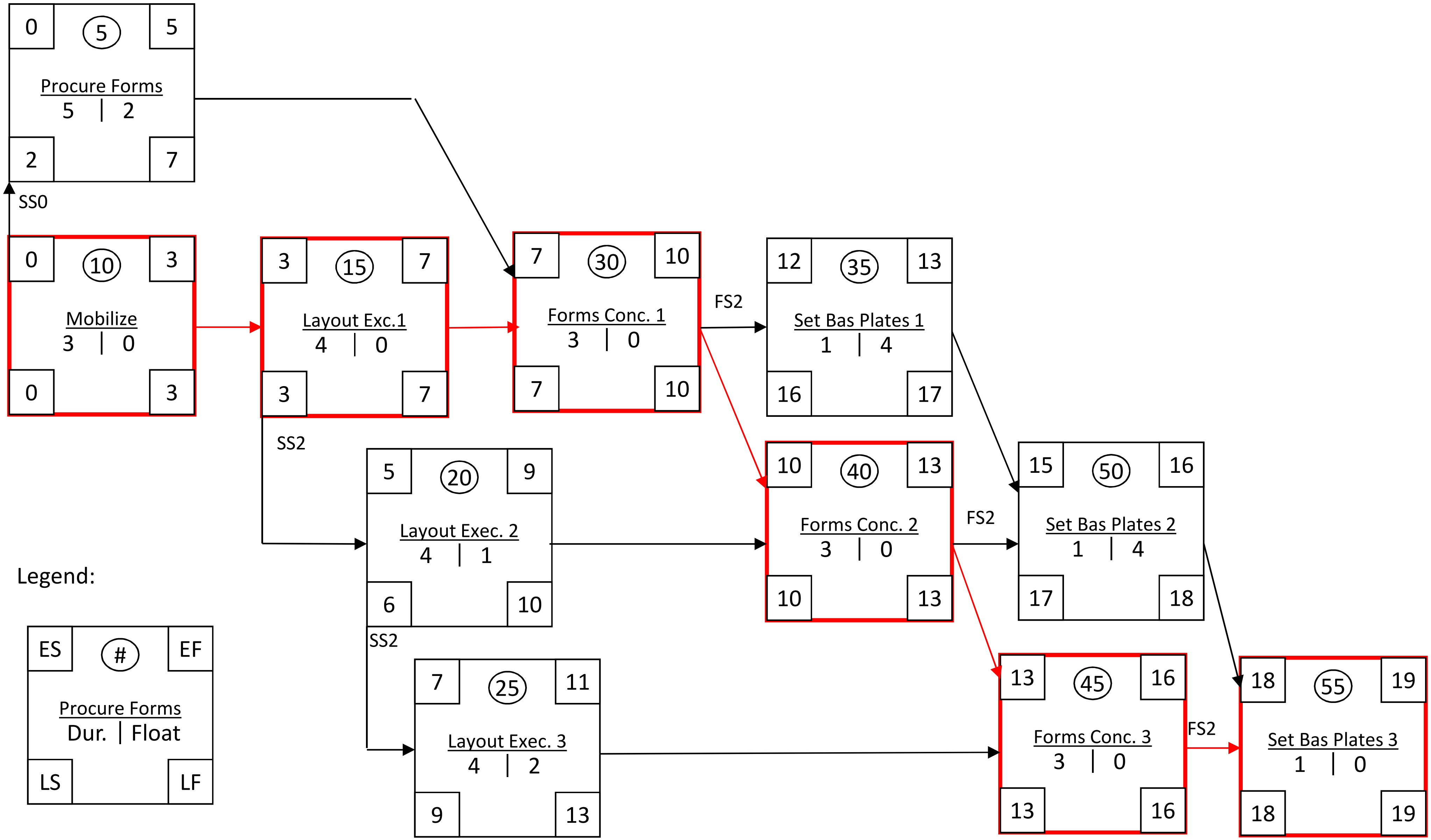


Total Float Calculation

Total Float = Late Finish – Early Finish



Critical Path



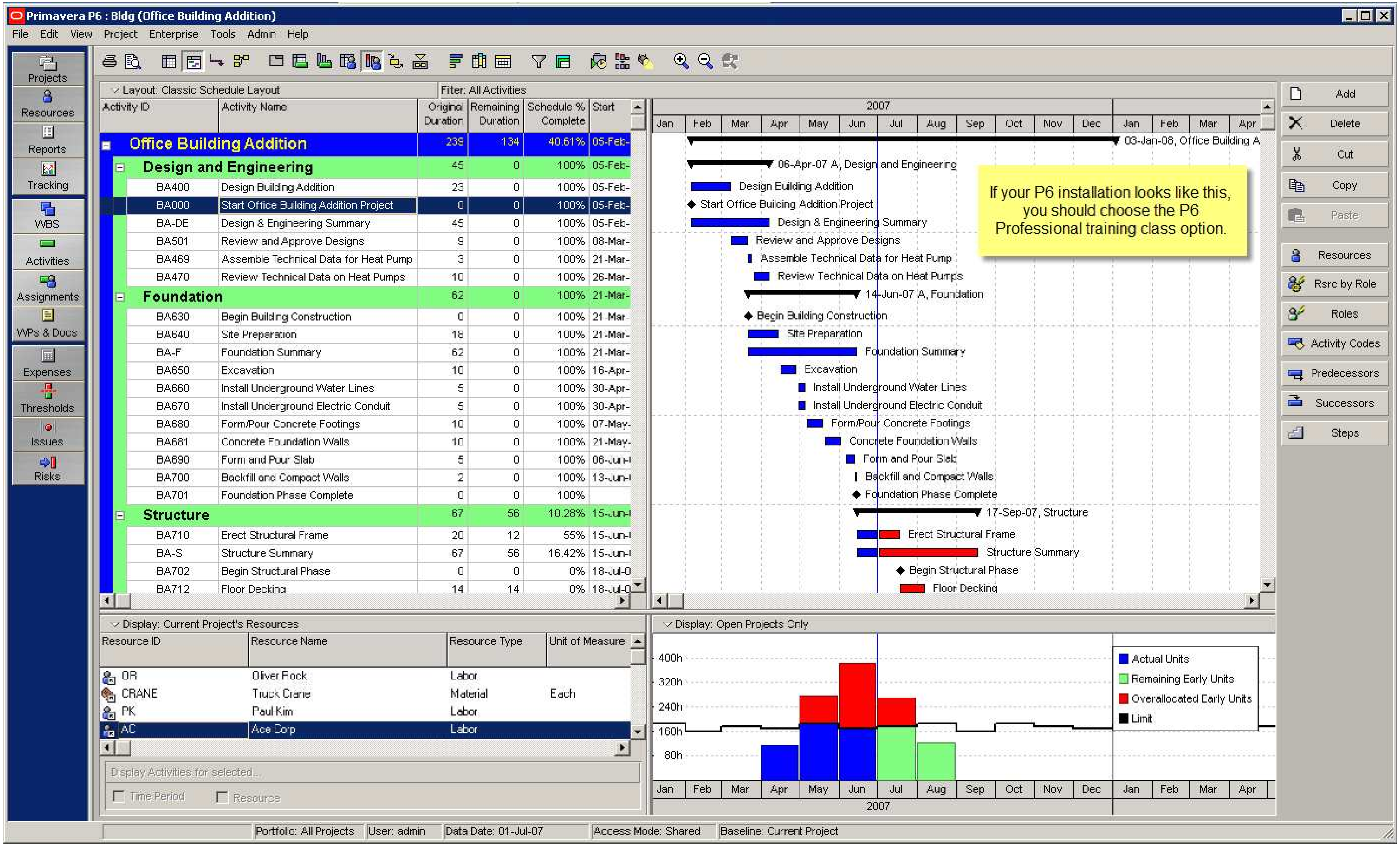
Project Scheduling – Schedule Development

- **Duration Compression**
  - Looks for ways to shorten the project schedule without changing the project scope
  - Fast Tracking: means you look at activities normally done in sequence and assign them instead partially in parallel. For instance, you would start construction in areas where you felt the design was pretty solid without waiting for the entire design to be completed. **Rework and Risk ↑**
  - Crashing: means to throw additional resources with additional costs to the critical path without necessarily getting the highest level of efficiency. For instance, you might add a second worker to the activity usually performed by one worker. **Cost ↑**

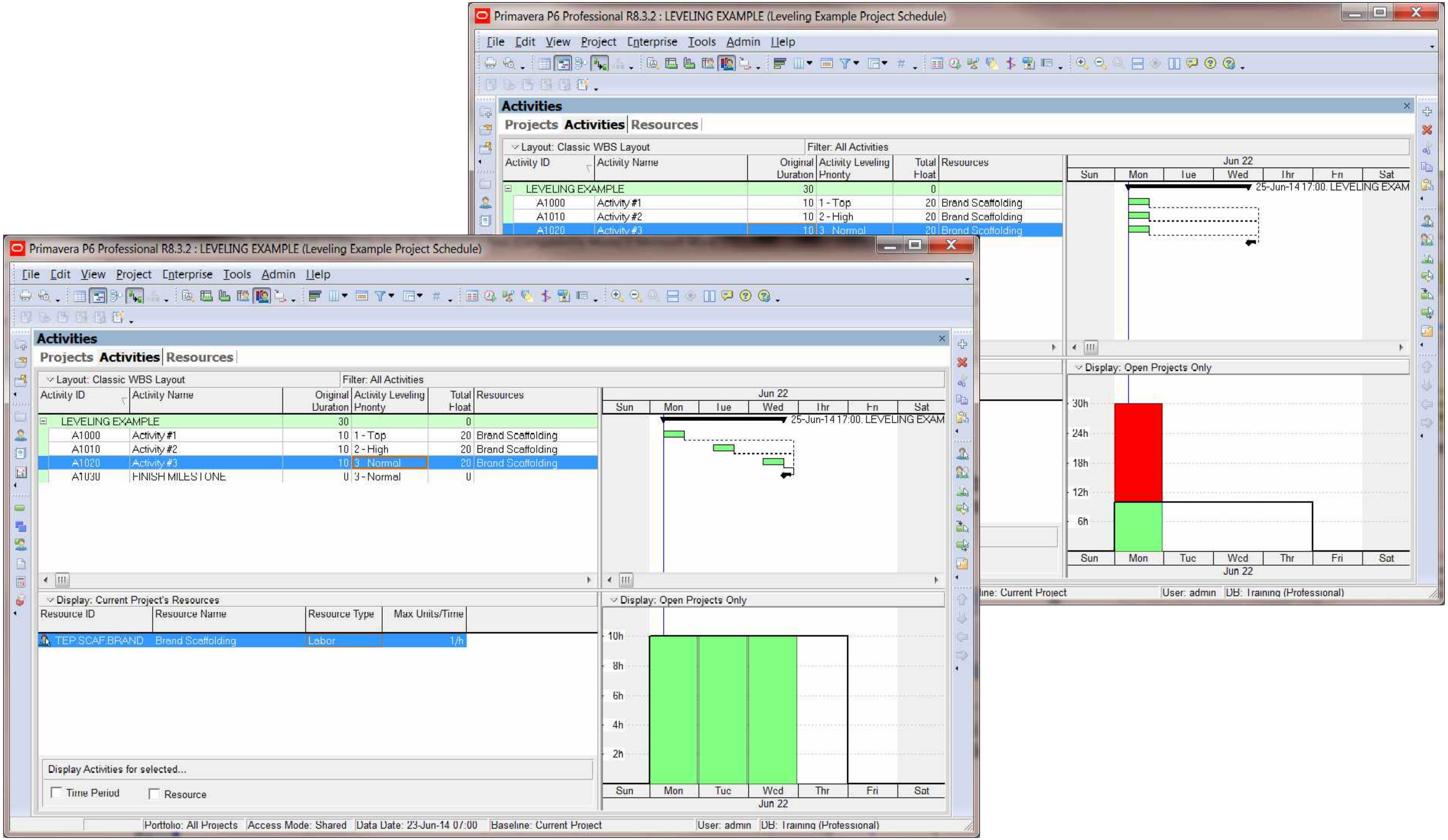
Project Scheduling – Schedule Control

- **Controlling changes to the project schedule**
- **Tools and Techniques**
  - Schedule change control system: includes the paperwork, tracking systems, and approval levels
  - Performance measurement: assesses the magnitude of any variations
  - Additional planning: due to prospective changes

Project Scheduling – Schedule Control



Project Scheduling – Schedule Control



In-Class Scheduling Exercise

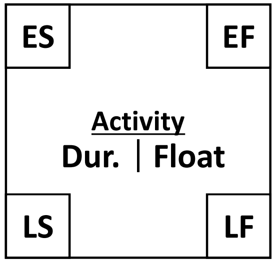
- **Project Start Date: 5/1/2020**

Code Value	Code Title
GC	General Contractor
PC	Plumbing Contractor
EC	Electrical Contractor
RC	Roofing Contractor

Activity	Description	Duration	Predecessor	Code
10	Mobilization	1		GC
20	Excavation	2	10	GC
30	Place gravel	2	20	GC
40	Place slab forms	3	20	GC
50	Place rebar	2	30	GC
60	Rough in plumbing	2	50	PC
70	Pour & cure concrete	9	40, 60	GC
80	Remove forms	2	70	GC
90	Erect frame & sheath walls	4	70	GC
100	Sheath roof	3	80, 90	RC
110	Electrical	3	100	EC
120	Install siding	4	100	GC
130	Finish carpentry	3	100	GC
140	Finish roof & flashing	3	100	RC
150	Paint	5	110, 120, 130	GC
160	Clean-up	2	140, 150	GC

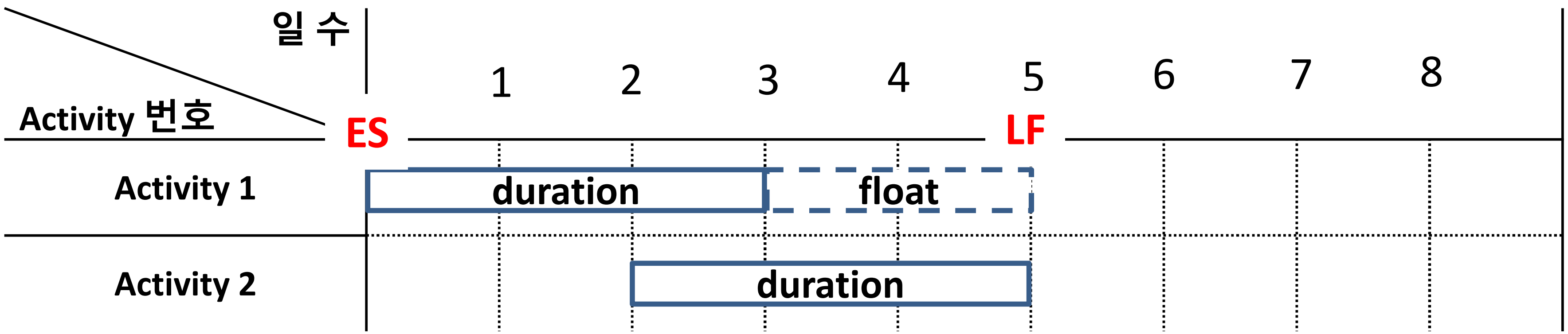
In-Class Exercise

1. Draw the precedence diagram network
2. Use CPM calculations to determine the project duration



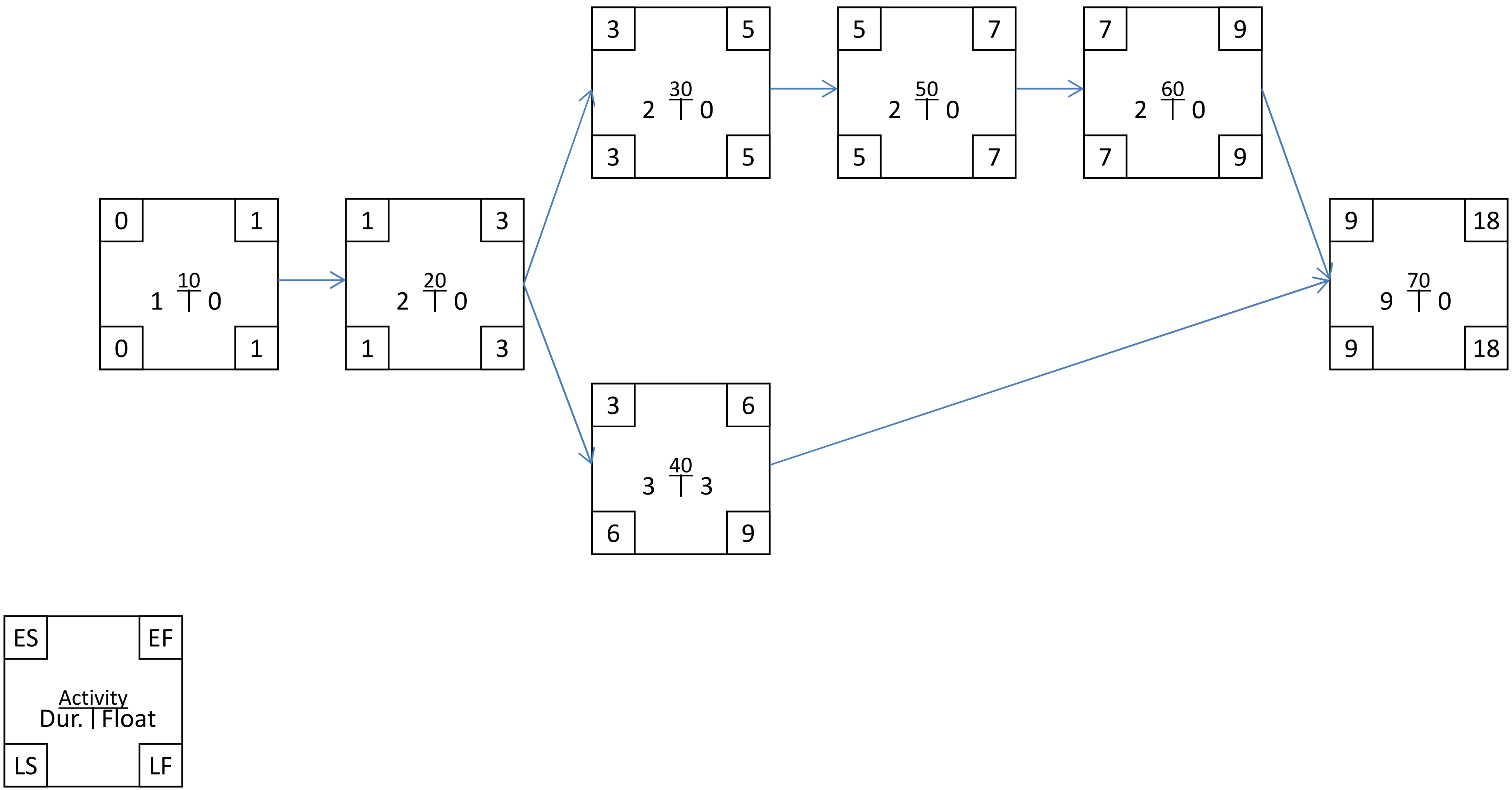
3. Develop a Gantt chart

[예시]



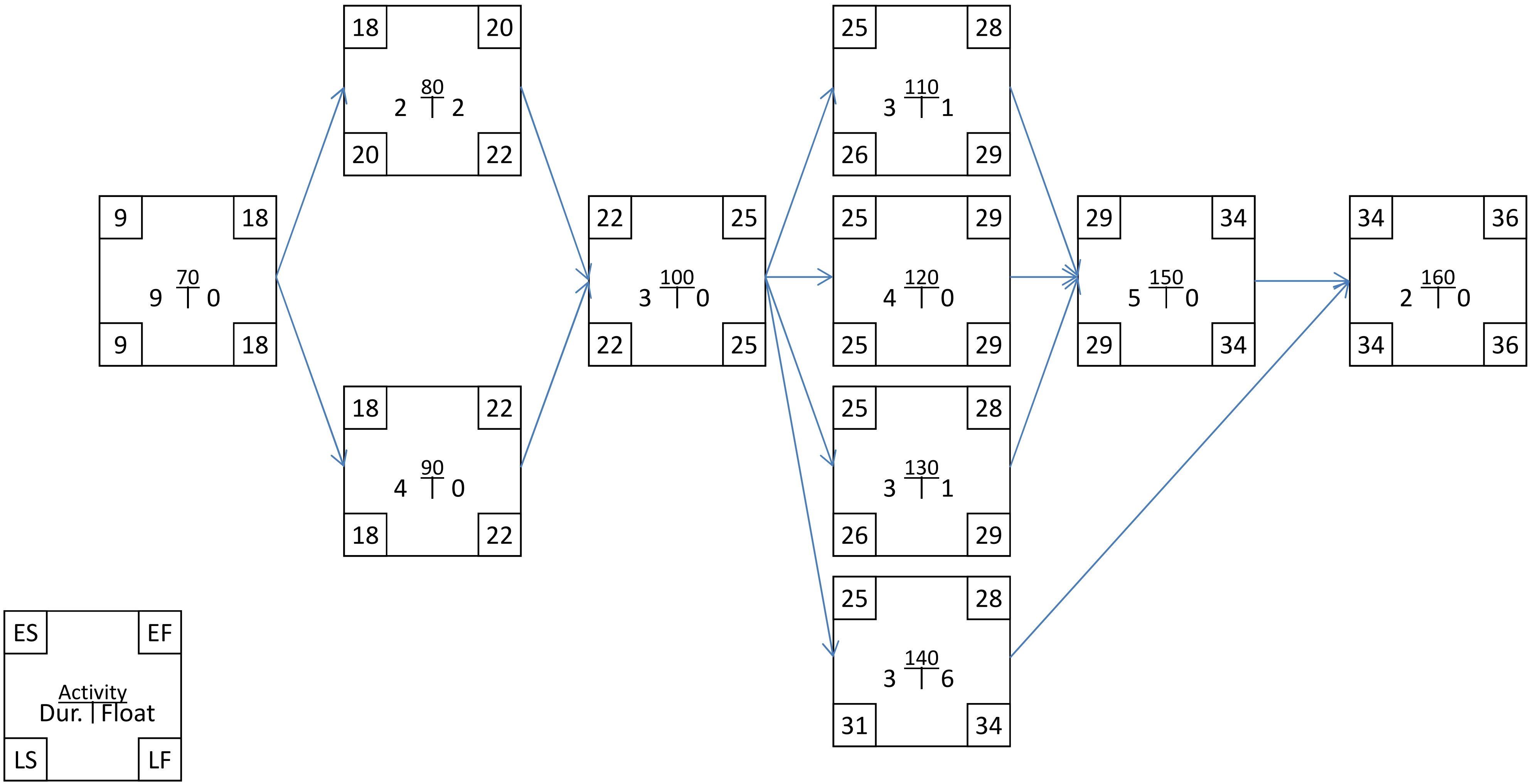
In-Class Scheduling Exercise

1. Draw the precedence diagram network



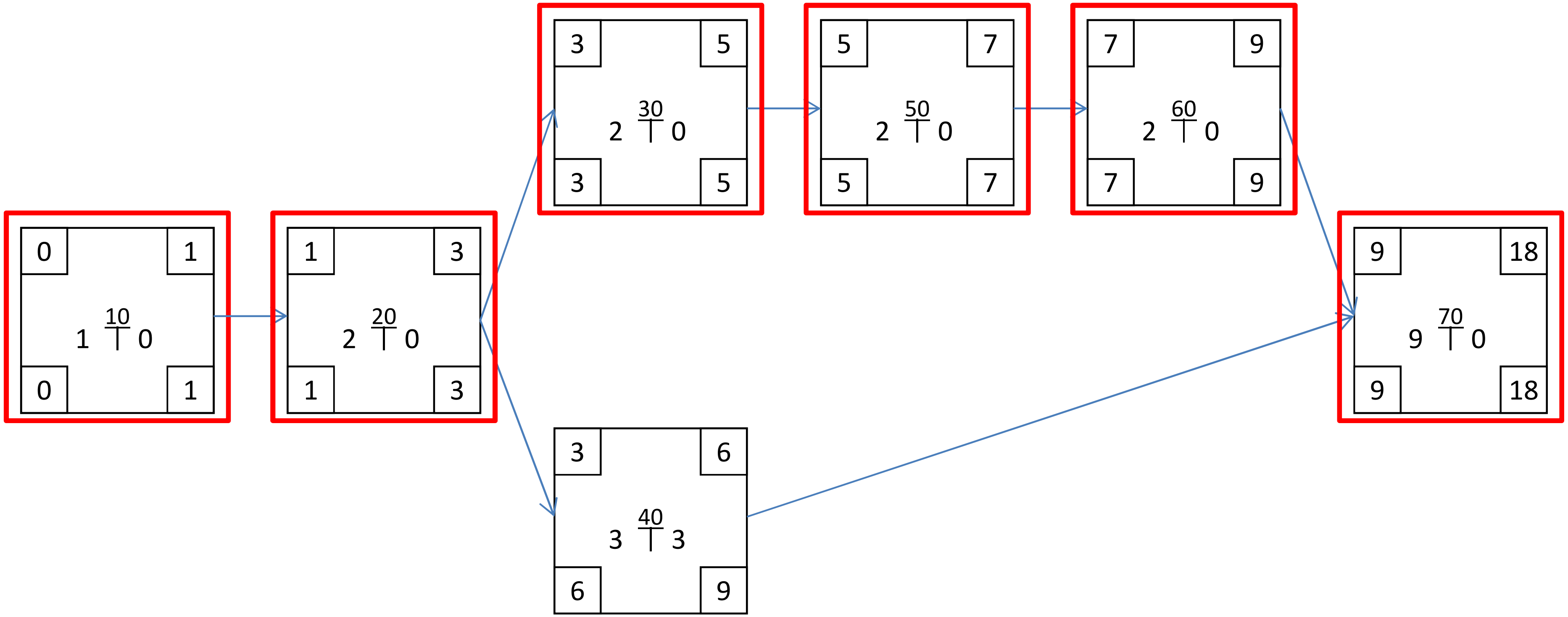
In-Class Scheduling Exercise

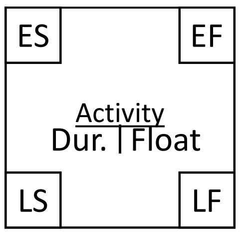
1. Draw the precedence diagram network



In-Class Scheduling Exercise

2. Determine the project duration

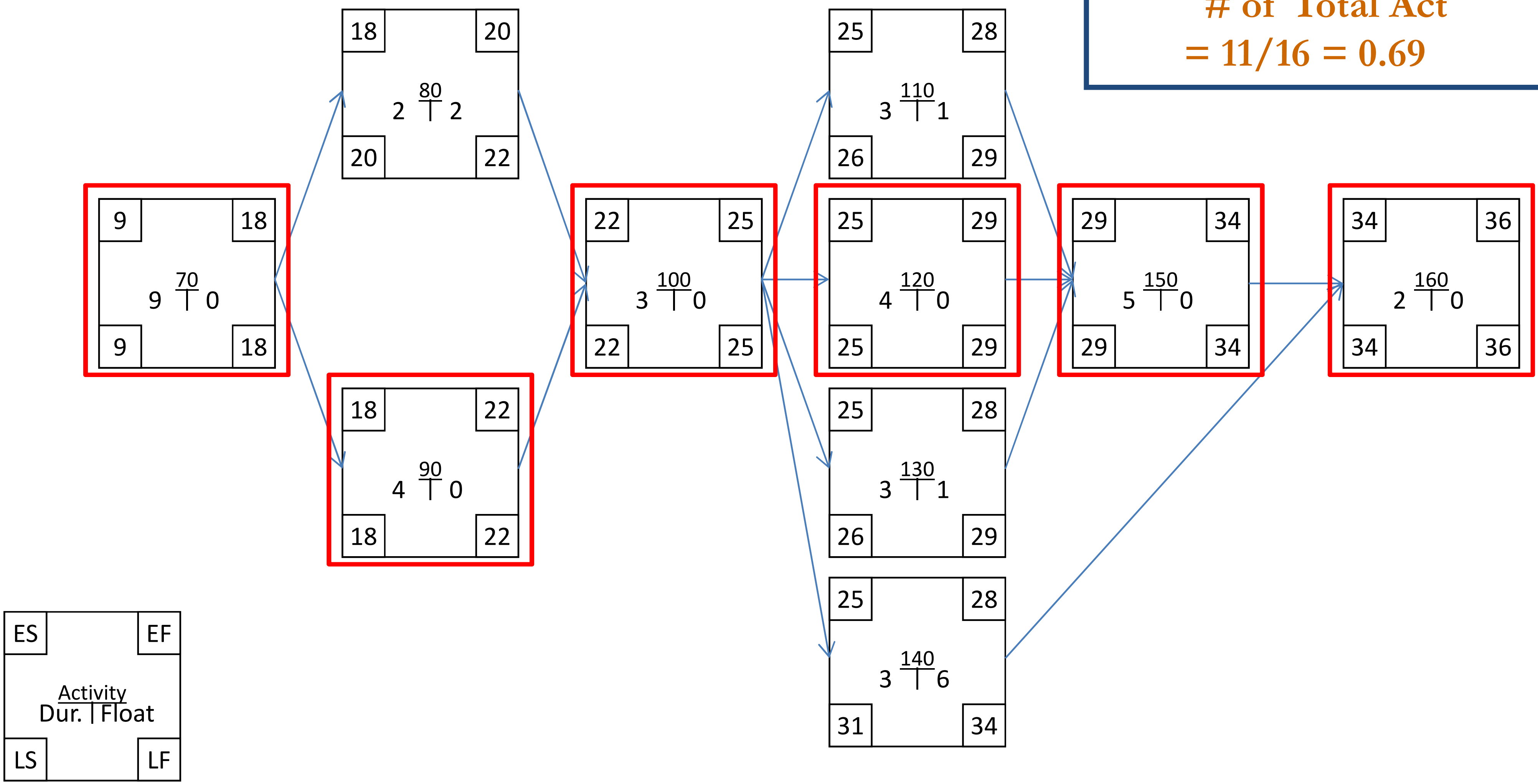




In-Class Scheduling Exercise

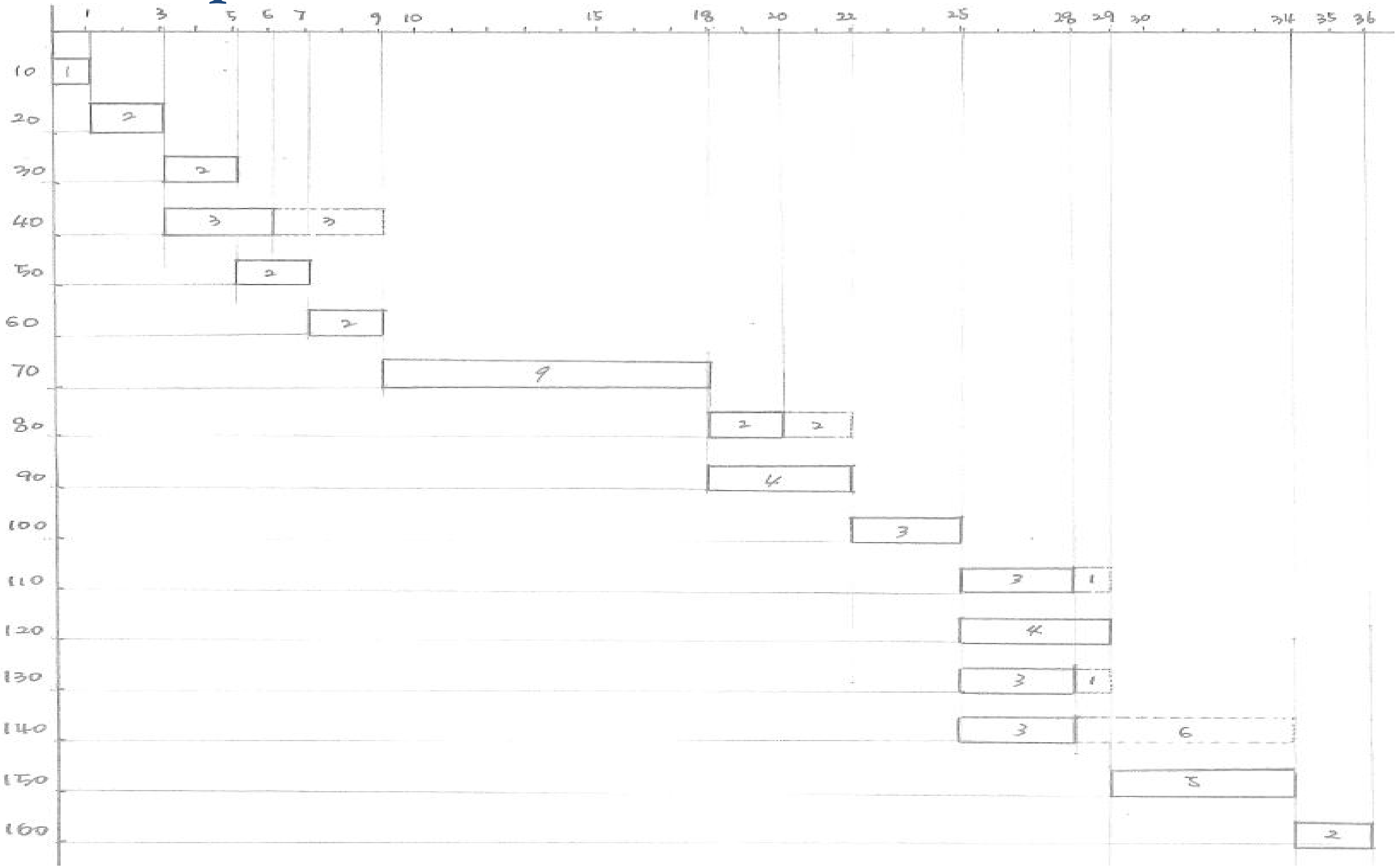
2. Determine the project duration

Duration: 36 days
C.I. = # of Critical Act / # of Total Act
= 11/16 = 0.69



In-Class Scheduling Exercise

3. Develop a Gantt chart



Week 6

Project Scheduling (2)

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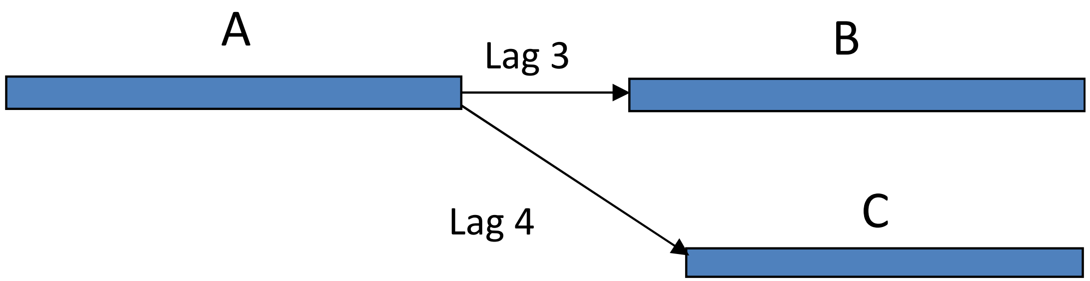
Total Float/Free Float

- **Total Float**
  - Most common
  - Amount of movement of an activity within a window before project completion delayed

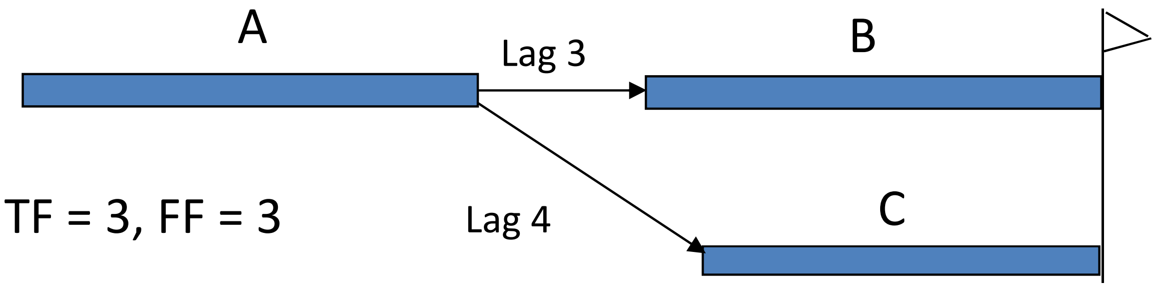
    e.g., 3 days are okay to be delayed without causing a problem on a completion date
- **Free Float**
  - Amount of movement within window before start of any succeeding activity is delayed
  - ***e.g., 3 days are okay to be delayed without causing a problem on any succeeding activity***

Free Float/Total Float Comparison



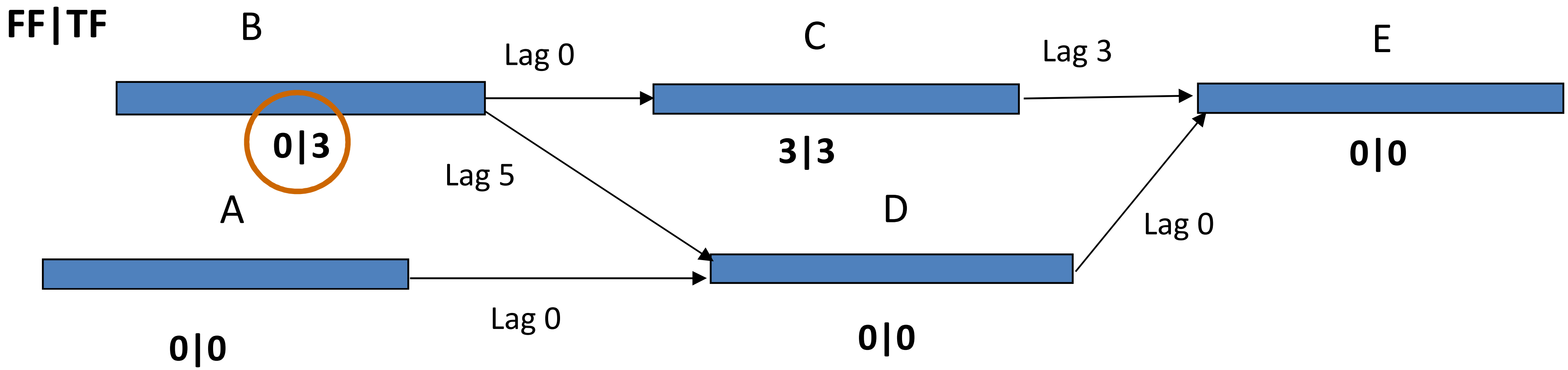
Free float = min lag = 3

Total float = ??? → why? ***Don't know completion date***



TF = 3, FF = 3

Free Float/Total Float Comparison



A, D, E on critical path

C has TF = FF = 3 → why? ***E has TF = FF = 0***

B has TF = 3 when FF = 0 → why?

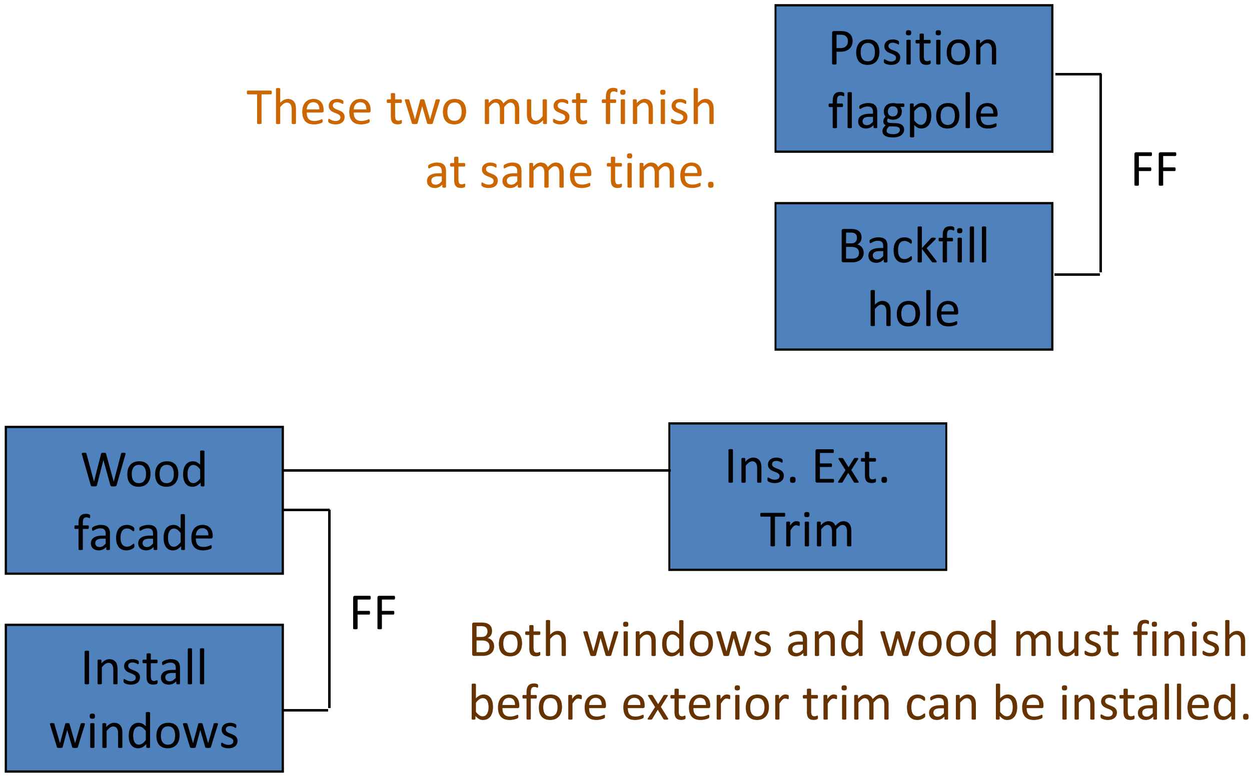
C has TF = FF = 3

Activity Relationships

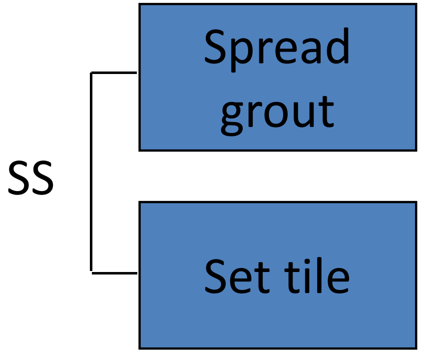
- **Logical connections in precedence networks**
  - Finish to Start (FS)
  - Start to Start (SS)
  - Finish to Finish (FF)
  - Start to Finish (SF)
- **FS by far most popular/used/understood**
- **Can include lags**
  - Lags are formal/required wait periods (e.g., concrete)

Finish to Finish

- Two activities must finish at same time

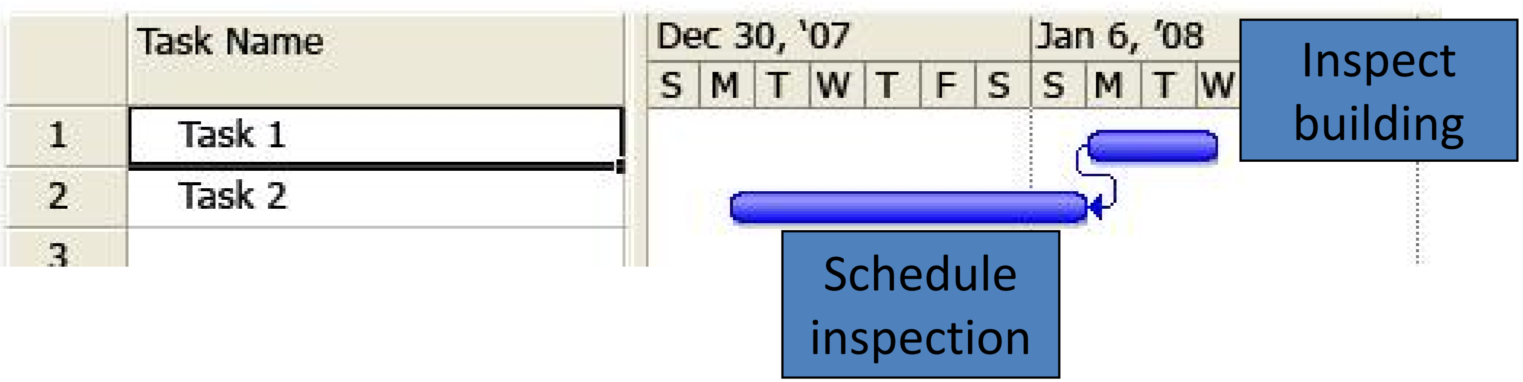


Start to Start & Start to Finish



These two must start at same time.
(But why wouldn't you just model them as one activity?)

Better resource allocation and management



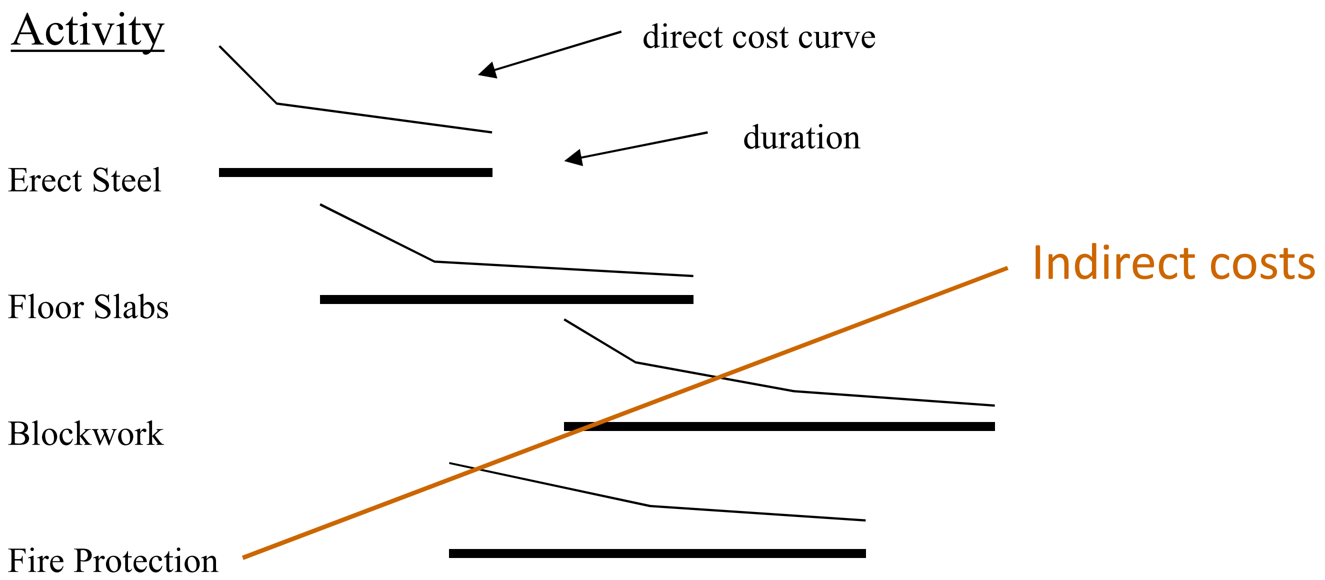
<u>SF is a tough one!</u> The start date of Task 1 determines the finish date of Task 2.
Usually used for procurement type activities.

Schedule Compression

- **Assumptions**
  - Direct costs
    - Are attached to activities
    - Increase with decreasing duration
  - Indirect costs
    - e.g., utilities, rent, audit and legal, administrative staffs, fuel, maintenance, security, telephone, etc.
    - Independent of activity duration
    - Decrease with project duration (linear costs)

Schedule Compression

- **Time-Cost Trade-Off**



Ignore indirect costs, so decrease duration by reducing Critical Path activities (why?) ***To get maximum impact on schedule***

General goal – start with lowest slope(cost/day) of cost curve (why?)

Lowest slope has lowest cost deviation

Schedule Compression

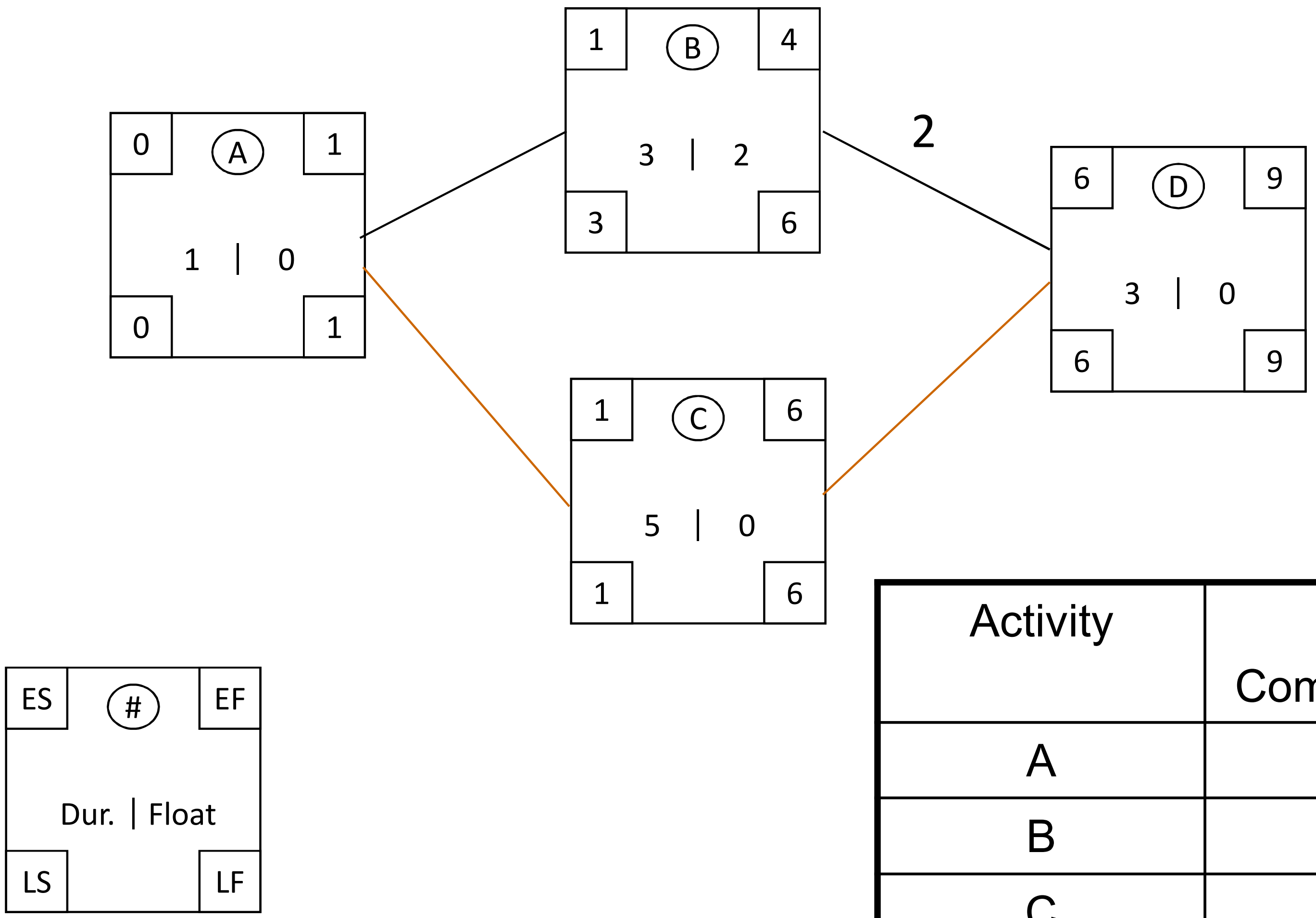
- **Some Terminology**
  - All normal: standard schedule, no compression
  - Least cost: compression where least amount of increase in cost
  - Least time: shortest possible project duration → reduce critical path activity
  - All crash: all activities shortened → cost is greater

Schedule Compression

- **Basic Steps in Compression**
  1. Compute schedule values for all normal schedule
  2. Select critical path activity with least slope for crash costs (Least amount of increase in cost per unit time)
  3. Reduce activity duration by minimum of following (= Network Interaction Limit, NIL):
     1. Max days activity can be compressed
     2. Min value of lags affected by activity compression

     NOTE: ***Min value of lags for the last activity is infinity!***
  4. Recalculate schedule (=new all normal) with compressed activity duration (= NIL)
  5. Schedule requirements met? Yes → End, No → Step 2

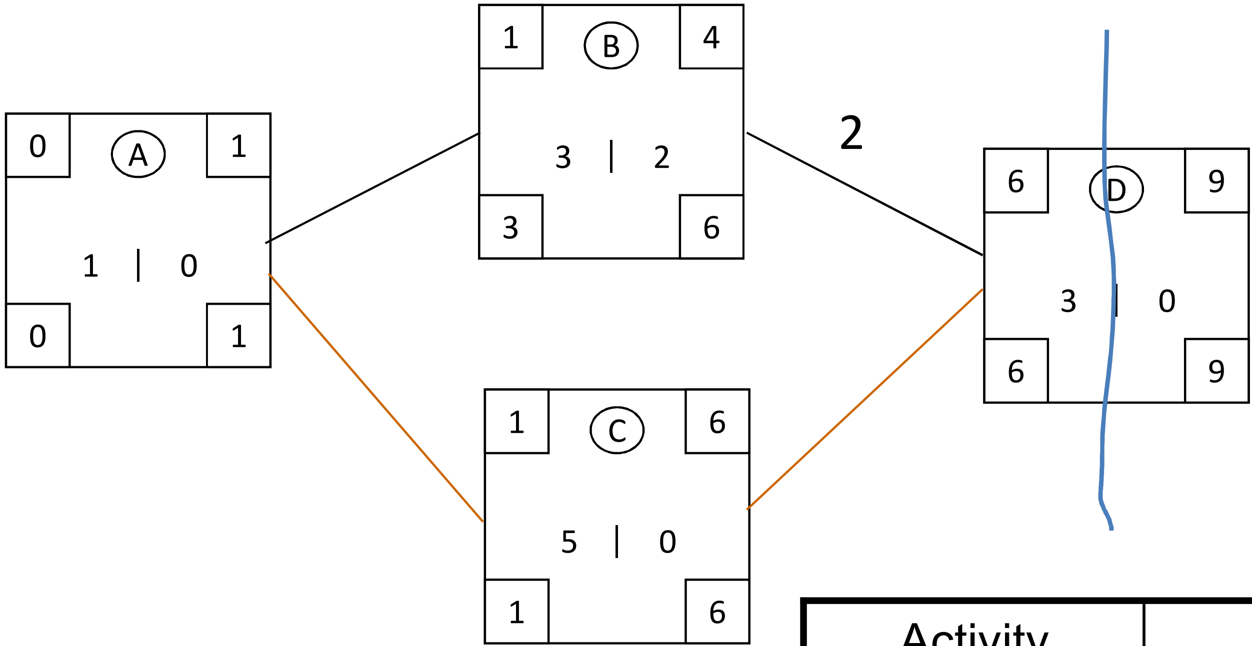
Schedule Compression Example (1)



Activity	Max Compression	Cost/Day
A	0	infinite
B	1	$400
C	3	$300
D	2	$150

Target: shortest possible schedule

Schedule Compression Example (1)



Activity	Max Compression	Cost/Day
A	0	infinite
B	1	$400
C	3	$300
D	2	$150

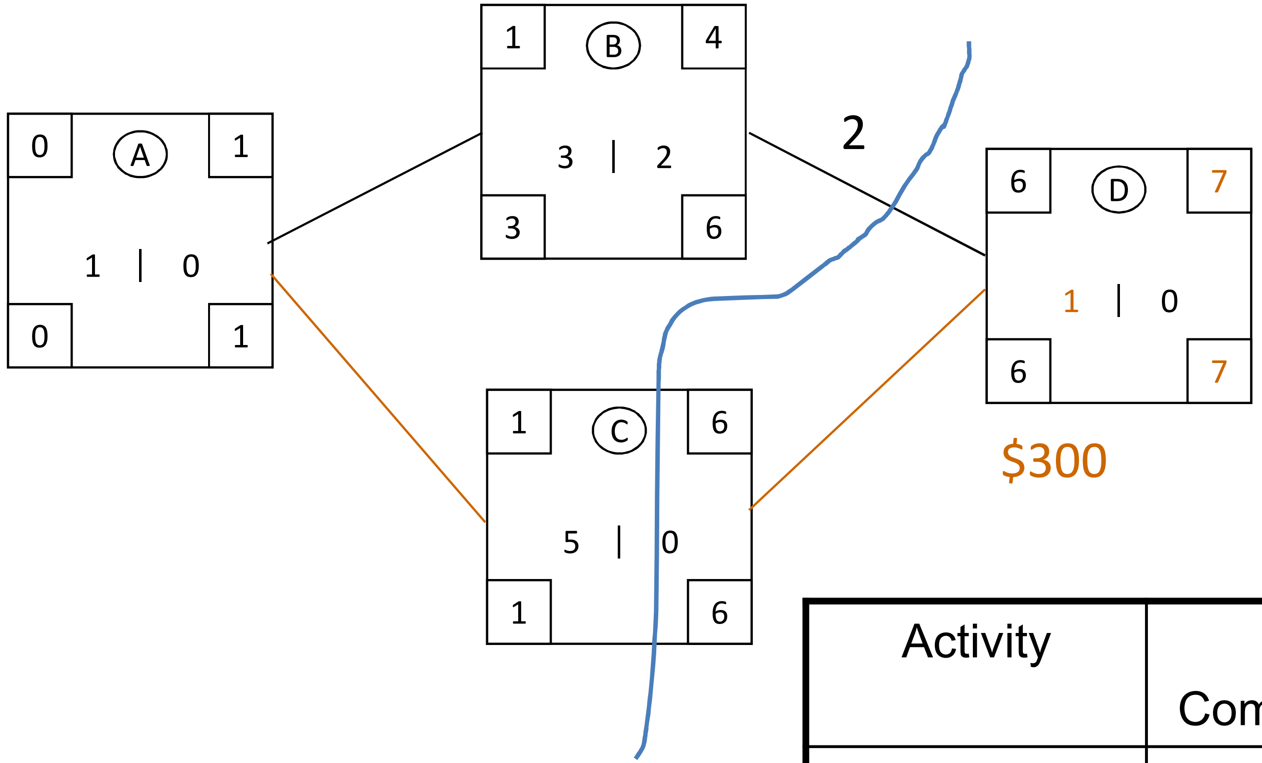
D has least slope (cost).

NIL(D) = min(2, Infinity) = 2

Min(Max days activity can be compressed,
Min value of lags affected by activity compression)

Recalculate

Schedule Compression Example (1)



Activity	Max Compression	Cost/Day
A	0	infinite
B	1	$400
C	3	$300
√D	0	$150

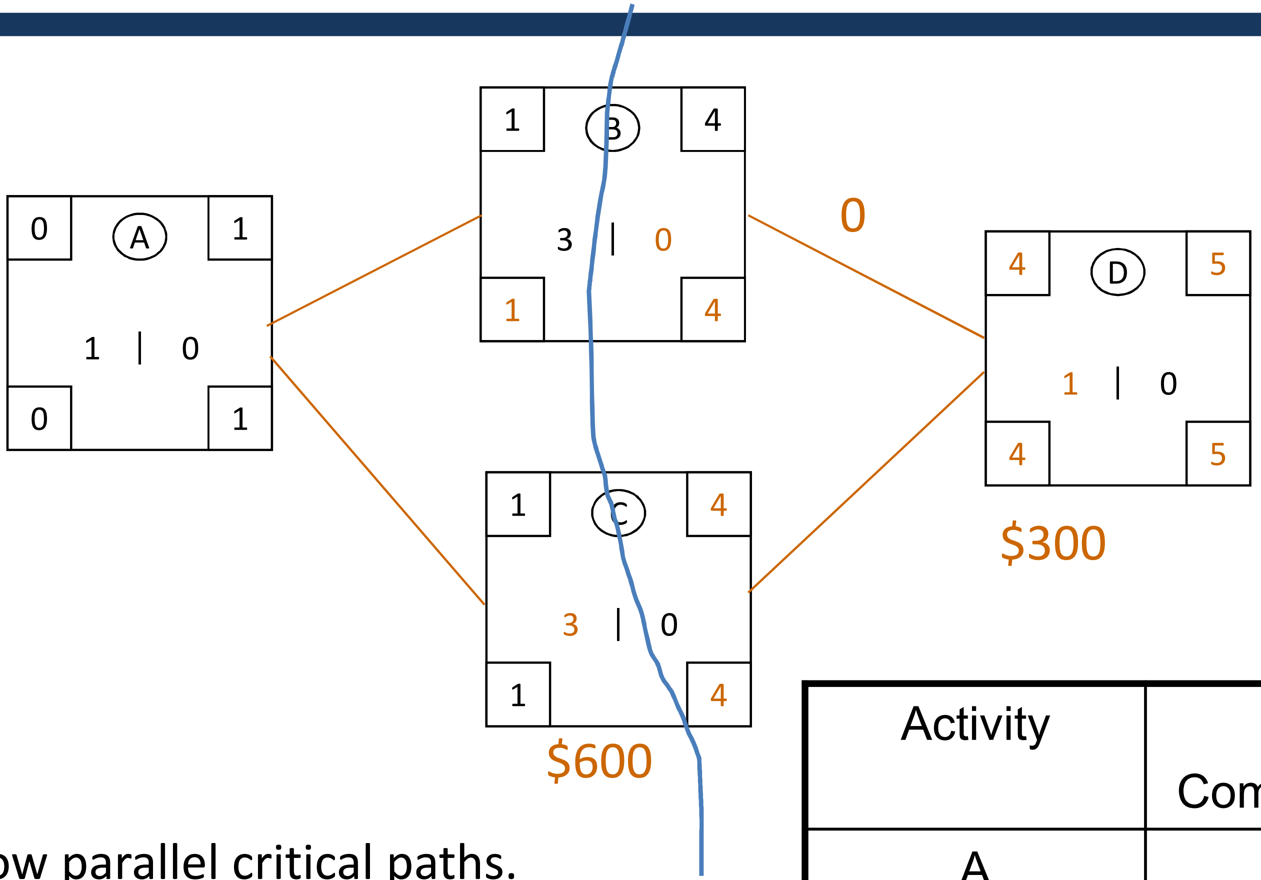
C has least cost

NIL(C) = min(3, 2) = 2

Min(Max days activity can be compressed,
Min value of lags affected by activity compression)

Recalculate

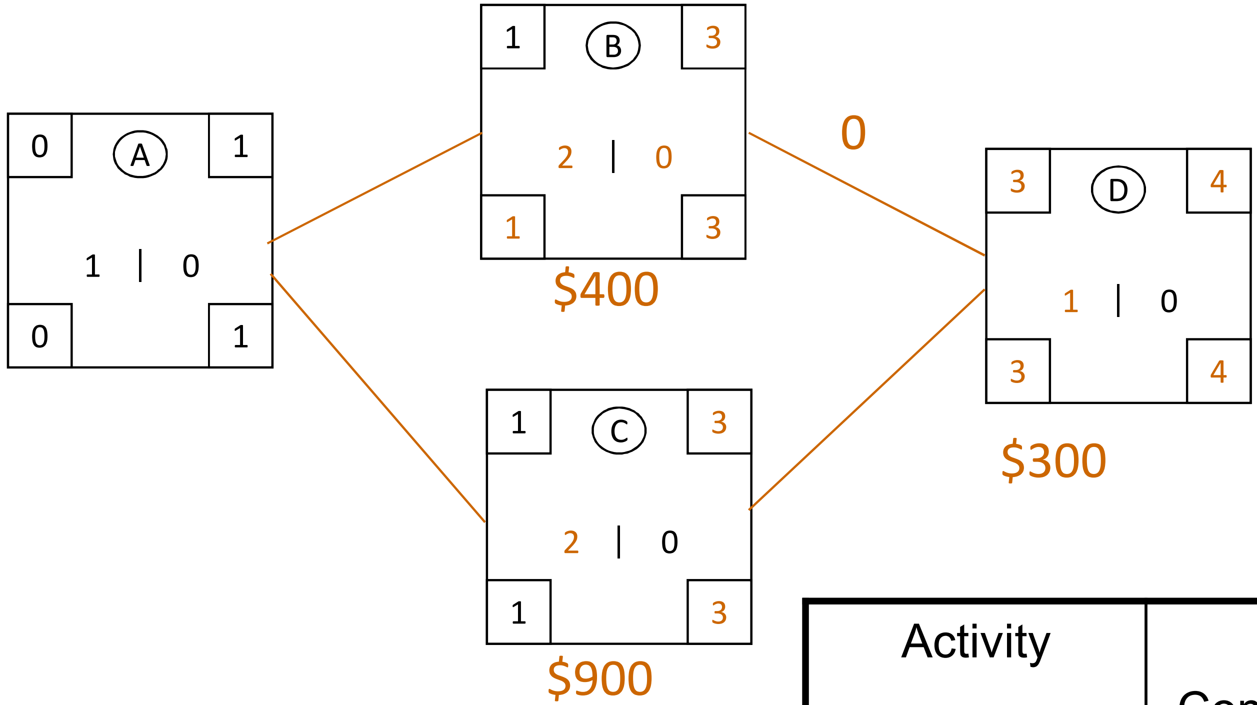
Schedule Compression Example (1)



B & C now parallel critical paths.
NIL (B,C) = min(1, infinite) = 1
Recalculate

Activity	Max Compression	Cost/Day
A	0	infinite
B	1	$400
√C	1	$300
√D	0	$150

Schedule Compression Example (1)

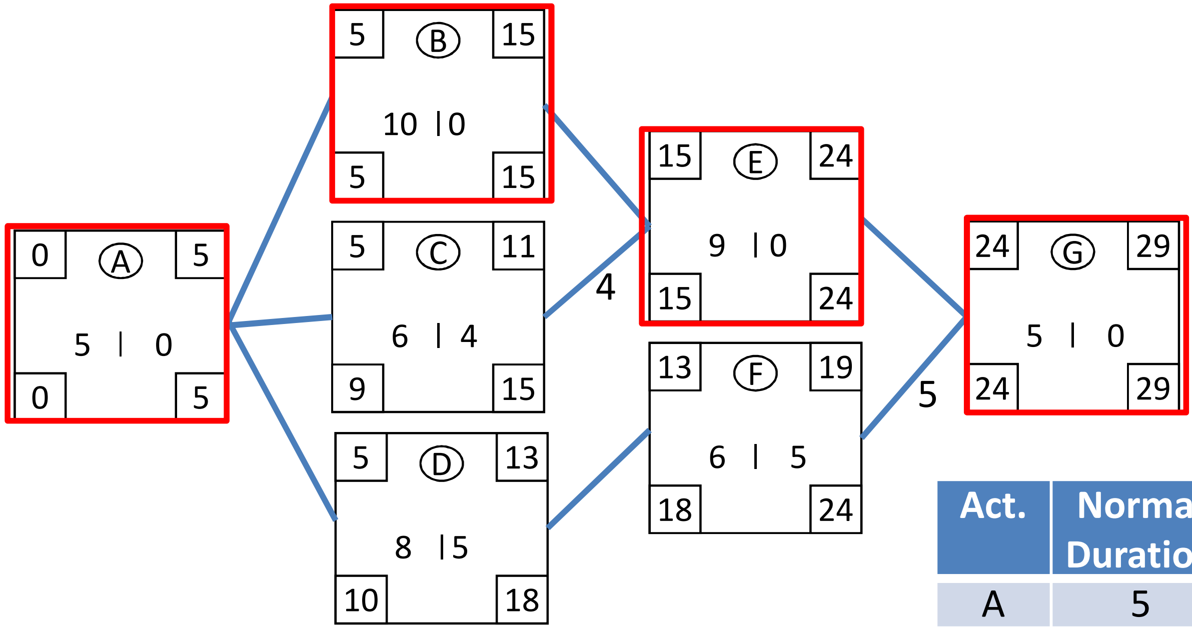


Total cost = $1,600
Total compression = 5 days
Total duration = 4 days

Activity	Max Compression	Cost/Day
A	0	infinite
√B	0	$400
√C	0	$300
√D	0	$150

- **Crash Cost =** Normal cost + slope
- **Crash Duration =** Normal Duration – Day to shorten
- **Cost for Cycle =** Cost per day * Days shorten

Schedule Compression Example (2)



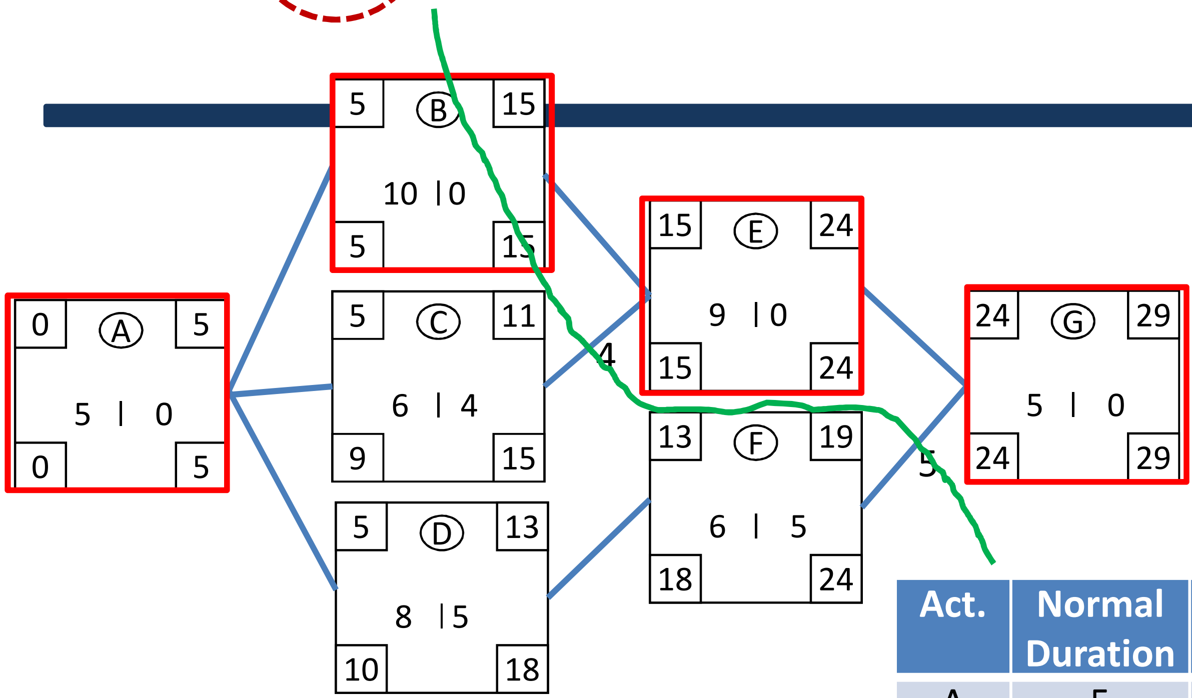
A	B	E	G
∞	$20	$55	$40

Act.	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Day to Shorten	Slope ($/Day)
A	5	5	$100	$100	0	--
B	10	7	$500	$560	3	$20
C	6	4	$300	$400	2	$50
D	8	6	$400	$600	2	$100
E	9	5	$200	$420	4	$55
F	6	5	$100	$150	1	$50
G	5	3	$320	$400	2	$40

Cycle	Act	Can be shorten	NIL	Days shorten	Cost per day	Cost for cycle	Total cost	Project Duration
0							$1,920	29

A	B	E	G
∞	$20	$55	$40

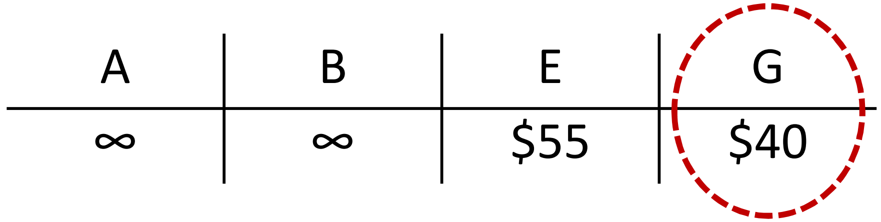
Example (2)



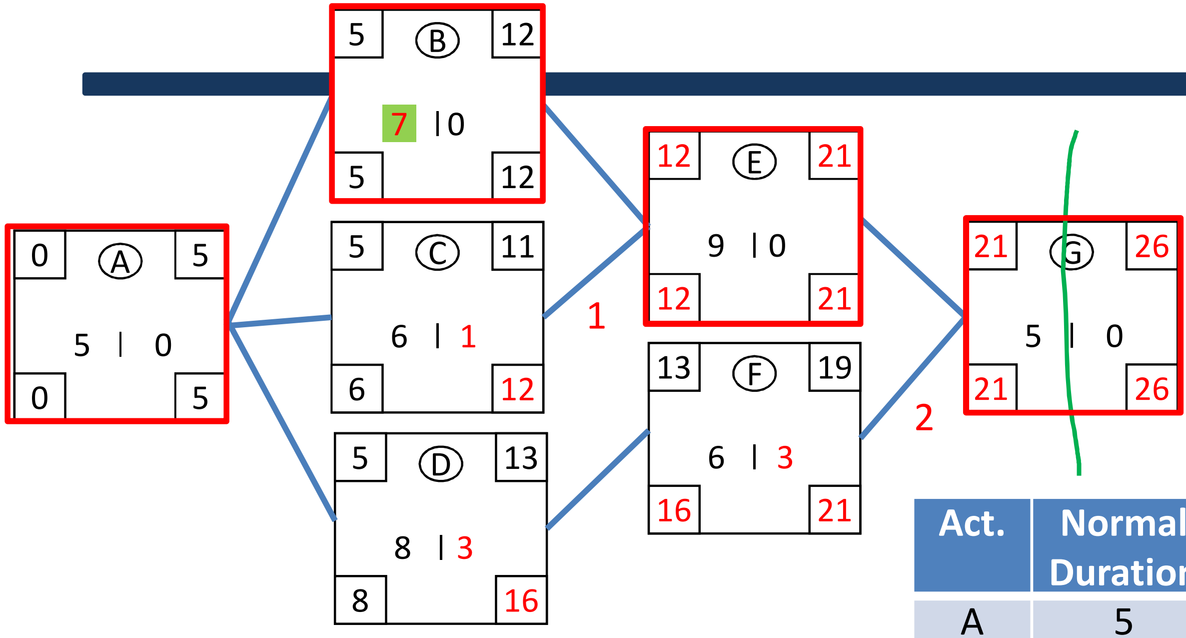
Act.	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Day to Shorten	Slope ($/Day)
A	5	5	$100	$100	0	--
B	10	7	$500	$560	3	$20
C	6	4	$300	$400	2	$50
D	8	6	$400	$600	2	$100
E	9	5	$200	$420	4	$55
F	6	5	$100	$150	1	$50
G	5	3	$320	$400	2	$40

min(3, 4) = 3

Cycle	Act	Can be shorten	NIL	Days shorten	Cost per day	Cost for cycle	Total cost	Project Duration
0							$1,920	29
1	B	3	4	3	$20	$60	$1,980	26



Example (2)



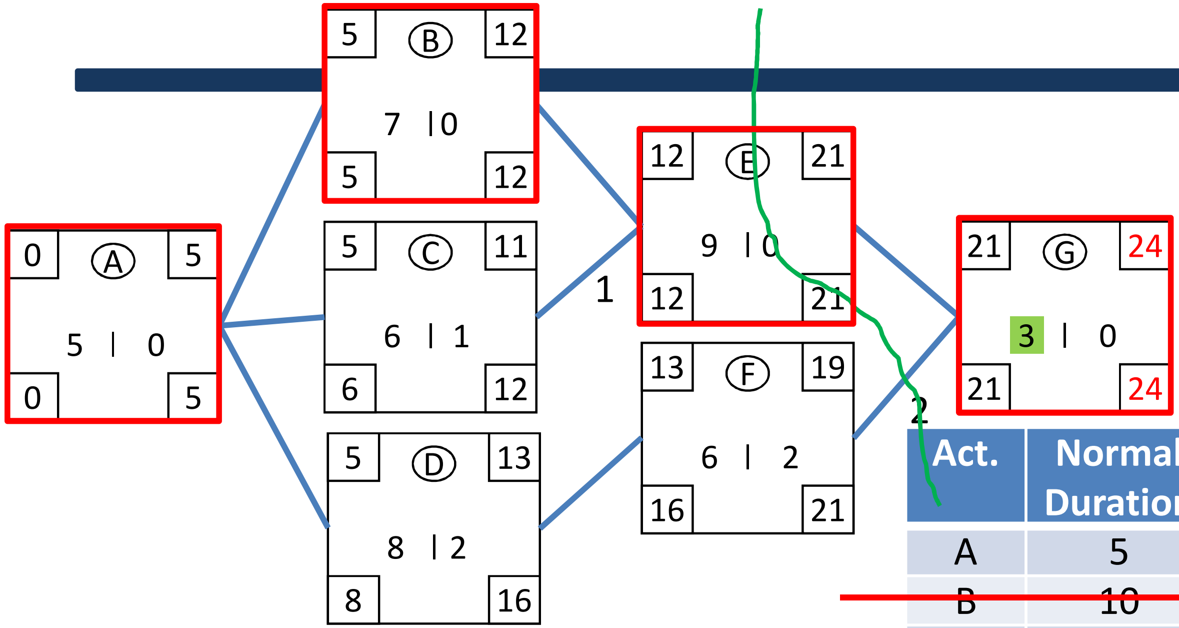
Act.	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Day to Shorten	Slope ($/Day)
A	5	5	$100	$100	0	--
~~B~~	~~10~~	~~7~~	~~$500~~	~~$560~~	~~0~~	~~$20~~
C	6	4	$300	$400	2	$50
D	8	6	$400	$600	2	$100
E	9	5	$200	$420	4	$55
F	6	5	$100	$150	1	$50
G	5	3	$320	$400	2	$40

min(2, ∞) = 2

Cycle	Act	Can be shorten	NIL	Days shorten	Cost per day	Cost for cycle	Total cost	Project Duration
0							$1,920	29
1	B	3	4	3	$20	$60	$1,980	26
2	G	2	∞	2	$40	$80	$2,060	24

A	B	E	G
∞	∞	$55	∞

Example (2)



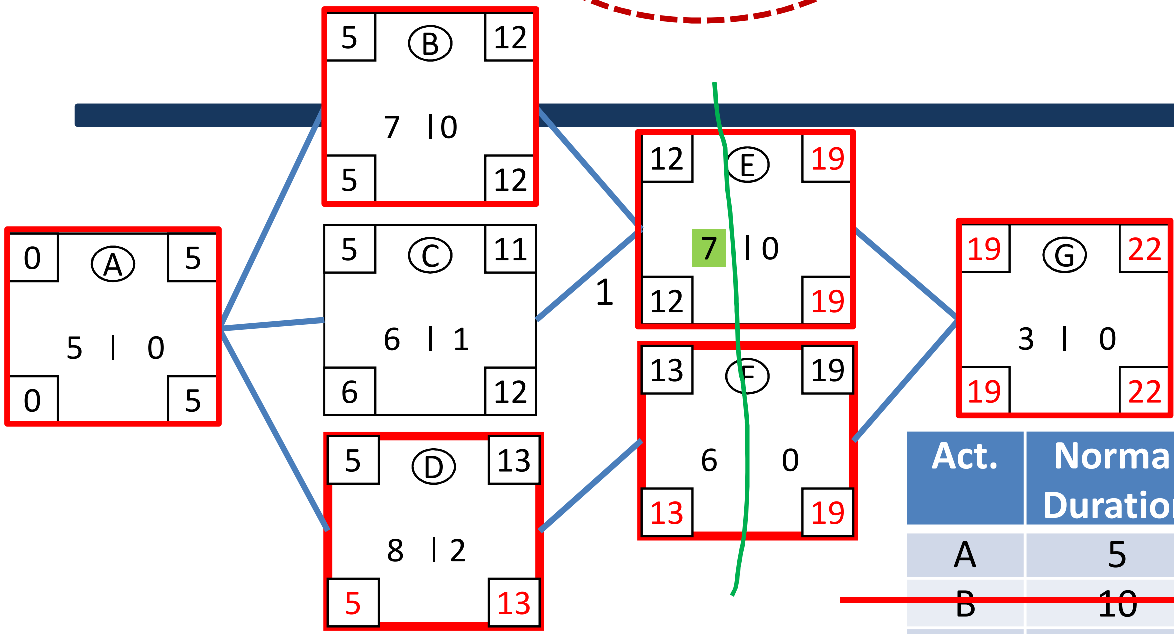
Act.	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Day to Shorten	Slope ($/Day)
A	5	5	$100	$100	0	--
~~B~~	~~10~~	~~7~~	~~$500~~	~~$560~~	~~0~~	~~$20~~
C	6	4	$300	$400	2	$50
D	8	6	$400	$600	2	$100
E	9	5	$200	$420	4	$55
F	6	5	$100	$150	1	$50
~~G~~	~~5~~	~~3~~	~~$320~~	~~$400~~	~~0~~	~~$40~~

min(4, 2) = 2

Cycle	Act	Can be shorten	NIL	Days shorten	Cost per day	Cost for cycle	Total cost	Project Duration
0							$1,920	29
1	B	3	4	3	$20	$60	$1,980	26
2	G	2	∞	2	$40	$80	$2,060	24
3	E	4	2	2	$55	$110	$2,170	22

Example (2)

A	B	D	E	F	G
∞	∞	$100	$55	$50	∞



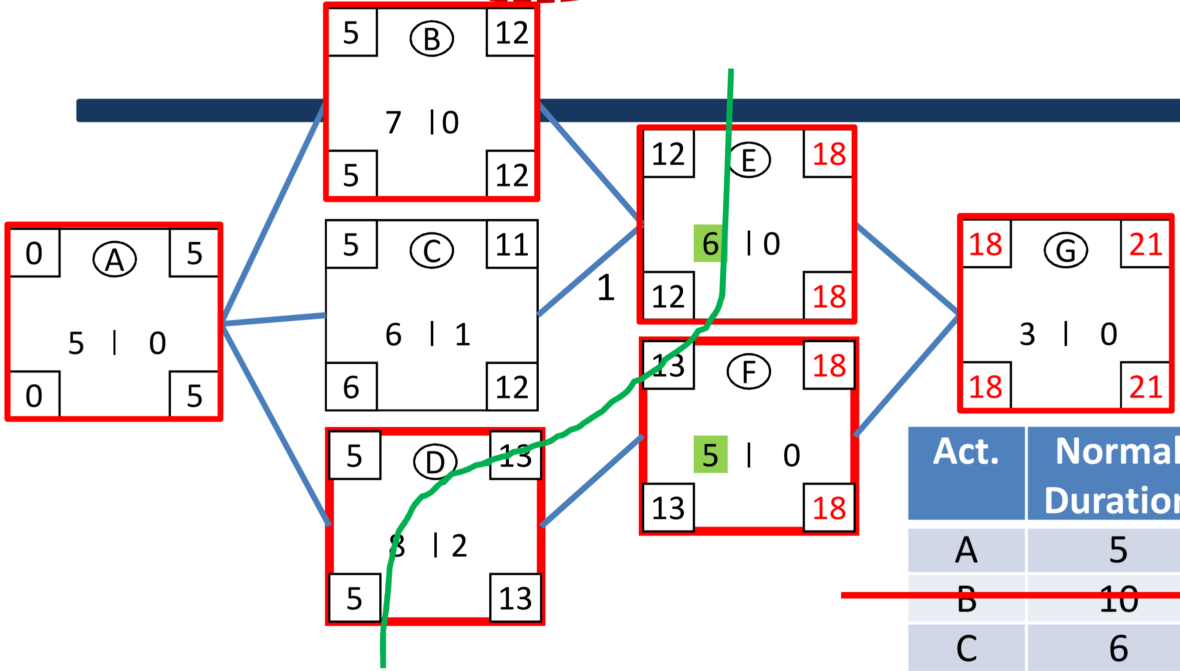
Act.	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Day to Shorten	Slope ($/Day)
A	5	5	$100	$100	0	--
~~B~~	~~10~~	~~7~~	~~$500~~	~~$560~~	~~3~~	~~$20~~
C	6	4	$300	$400	2	$50
D	8	6	$400	$600	2	$100
E	9	5	$200	$420	2	$55
F	6	5	$100	$150	1	$50
~~G~~	~~5~~	~~3~~	~~$320~~	~~$400~~	~~2~~	~~$40~~

min(1, ∞) = 1

Cycle	Act	Can be shorten	NIL	Days shorten	Cost per day	Cost for cycle	Total cost	Project Duration
0							$1,920	29
1	B	3	4	3	$20	$60	$1,980	26
2	G	2	∞	2	$40	$80	$2,060	24
3	E	4	2	2	$55	$110	$2,170	22
4	E+F	1	∞	1	$105	$105	$2,275	21

A	B	D	E	F	G
∞	∞	$100	$55	∞	∞

Example (2)



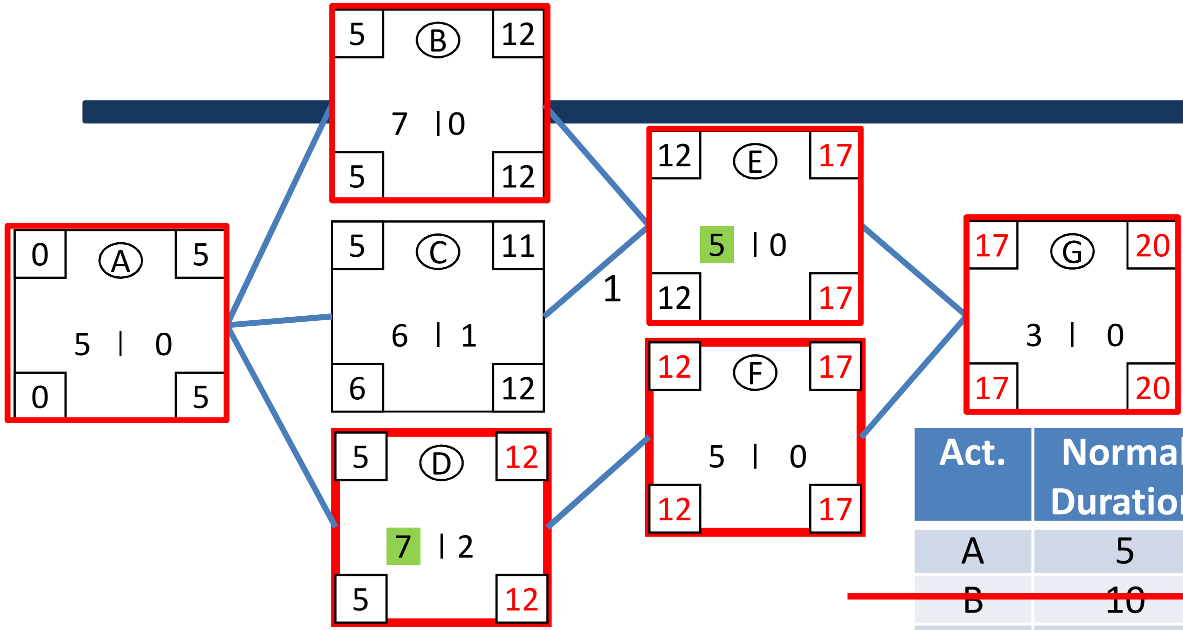
Act.	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Day to Shorten	Slope ($/Day)
A	5	5	$100	$100	0	--
~~B~~	~~10~~	~~7~~	~~$500~~	~~$560~~	~~0~~	~~$20~~
C	6	4	$300	$400	2	$50
D	8	6	$400	$600	2	$100
E	9	5	$200	$420	1	$55
~~F~~	~~6~~	~~5~~	~~$100~~	~~$150~~	~~0~~	~~$50~~
~~G~~	~~5~~	~~3~~	~~$320~~	~~$400~~	~~0~~	~~$40~~

min(1, ∞) = 1

Cycle	Act	Can be shorten	NIL	Days shorten	Cost per day	Cost for cycle	Total cost	Project Duration
0							$1,920	29
1	B	3	4	3	$20	$60	$1,980	26
2	G	2	∞	2	$40	$80	$2,060	24
3	E	4	2	2	$55	$110	$2,170	22
4	E+F	1	∞	1	$105	$105	$2,275	21
5	D+E	1	∞	1	$155	$155	$2,430	20

A	B	D	E	F	G
∞	∞	$100	∞	∞	∞

Example (2)



Act.	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Day to Shorten	Slope ($/Day)
A	5	5	$100	$100	0	--
~~B~~	~~10~~	~~7~~	~~$500~~	~~$560~~	~~0~~	~~$20~~
C	6	4	$300	$400	2	$50
D	8	6	$400	$600	1	$100
~~E~~	~~9~~	~~5~~	~~$200~~	~~$420~~	~~0~~	~~$55~~
~~F~~	~~6~~	~~5~~	~~$100~~	~~$150~~	~~0~~	~~$50~~
~~G~~	~~5~~	~~3~~	~~$320~~	~~$400~~	~~0~~	~~$40~~

Total crash cost = $510 (9-day crash)
Total duration = 20 days

Cycle	Act	Can be shorten	NIL	Days shorten	Cost per day	Cost for cycle	Total cost	Project Duration
0							$1,920	29
1	B	3	4	3	$20	$60	$1,980	26
2	G	2	∞	2	$40	$80	$2,060	24
3	E	4	2	2	$55	$110	$2,170	22
4	E+F	1	∞	1	$105	$105	$2,275	21
5	D+E	1	∞	1	$155	$155	$2,430	20

Week 6

In-Class Exercise

457.307 Construction Planning and Management

Department of Civil and Environmental Engineering

Seoul National University

Prof. Seokho Chi

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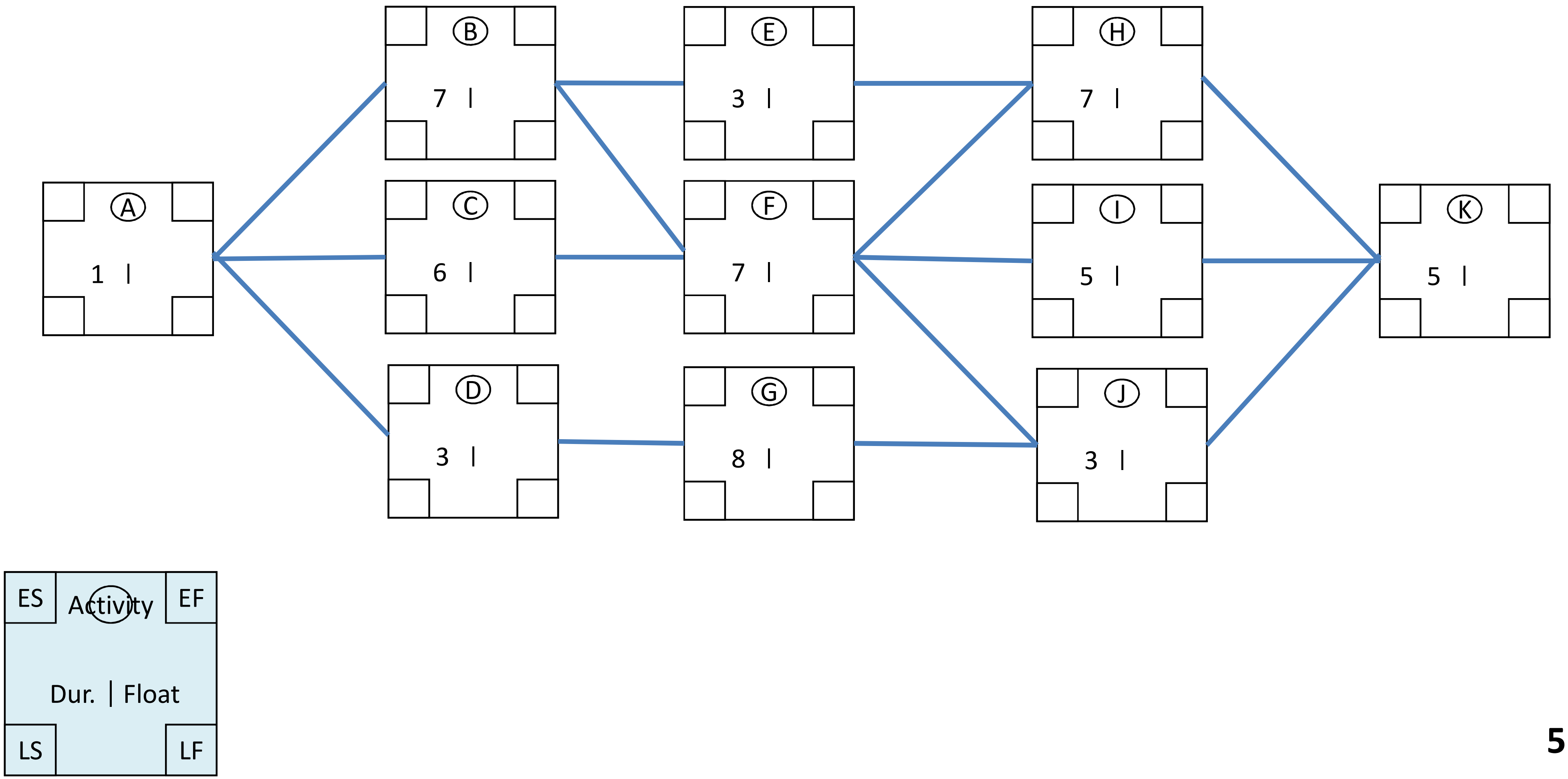
건설환경공학부 35동 304호

In-Class Exercise

1. Critical Path
2. Link lag



- **Crash Cost =** Normal cost + slope
- **Crash Duration =** Normal Duration – Day to shorten
- **Cost for Cycle =** Cost per day * Days shorten
- **Slope =** Cost per day

In-Class Exercise

Act.	Normal Duration	Crash Duration	Normal Cost	Crash Cost	Day to Shorten	Slope ($/Day)
A	1	1	$800	$800	0	--
B	7	4	$1,000	$1,600	3	$200
C	6	4	$300	$500	2	$100
D	3	2	$400	$800	1	$400
E	3	1	$100	$200	2	$50
F	7	5	$500	$800	2	$150
G	8	4	$200	$1,400	4	$300
H	7	6	$350	$600	1	$250
I	5	3	$700	$850	2	$75
J	3	2	$500	$1,000	1	$500
K	5	4	$450	$800	1	$350

Target: shortest possible schedule

1. For the activities on the critical path, pick the activity with least slope ($/day)
2. Reduce the duration
3. Fill out the table

Cycle	Act	Can be shorten	NIL	Days shorten	Cost per day	Cost for cycle	Total cost	Project Duration
0							$5,300	