Project Schedule Management

Philosophy

- The project manager should be in **control** of the schedule, and not vice versa
- The schedule is built from the ground up and **rigorously** managed throughout the life of the project
- The schedule should be as **flexible** as possible to accommodate the reality
- Schedule and cost are tightly linked

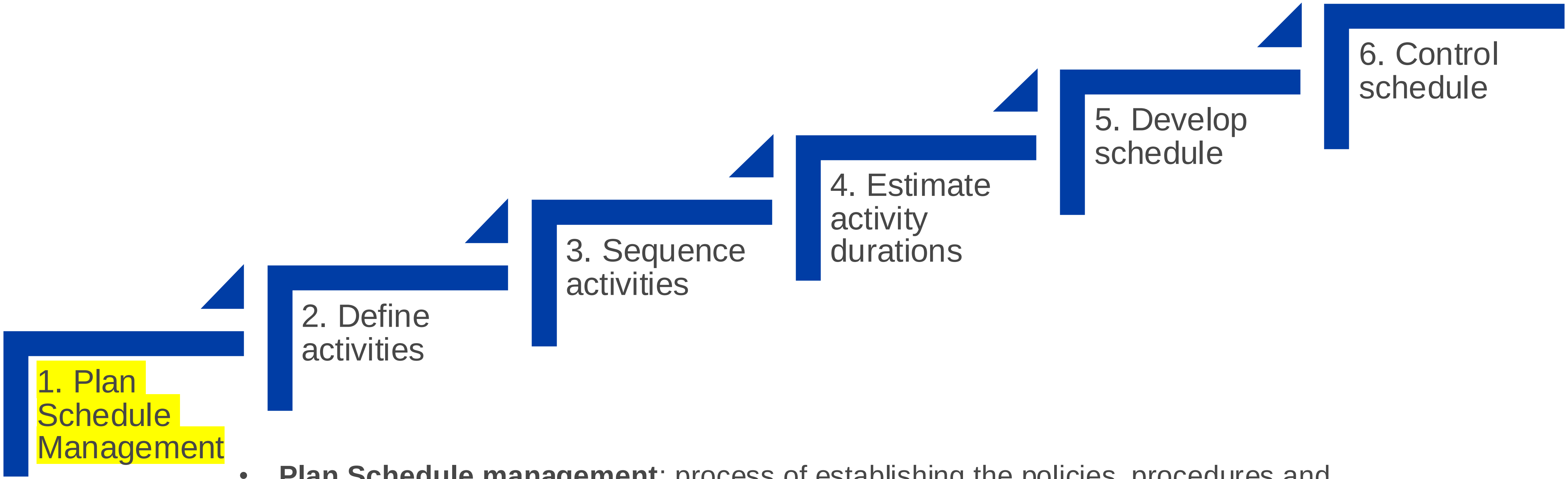
Scheduling process

1. Plan Schedule Management
   Establish policies, procedures and documentation
2. Define activities
   List the project activities
3. Sequence activities
   Order the activities and create the project network diagram
4. Estimate activity durations
   Determine time estimates for each activity
5. Develop schedule
   Create Schedule
6. Control schedule
   Monitor and adjust schedule performance

1. Plan schedule management

1

Plan schedule management



- **Plan Schedule management**: process of establishing the policies, procedures and documentation for planning, developing, managing, executing and controlling the project schedule
- **Schedule management plan**: scheduling methodology, release and iteration length, level of accuracy, control thresholds, reporting formats etc

2. Define activities

Define activities

1. Plan Schedule Management
2. Define activities
3. Sequence activities
4. Estimate activity durations
5. Develop schedule
6. Control schedule

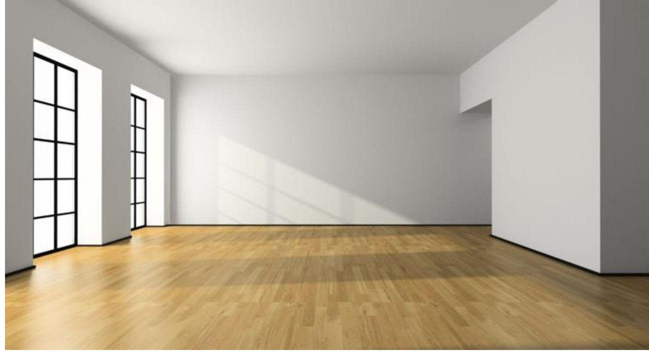
- **Define activities**: identify and document actions to produce the project deliverables
- **Activity**: a unique and distinct scheduled portion of work with a duration > 0

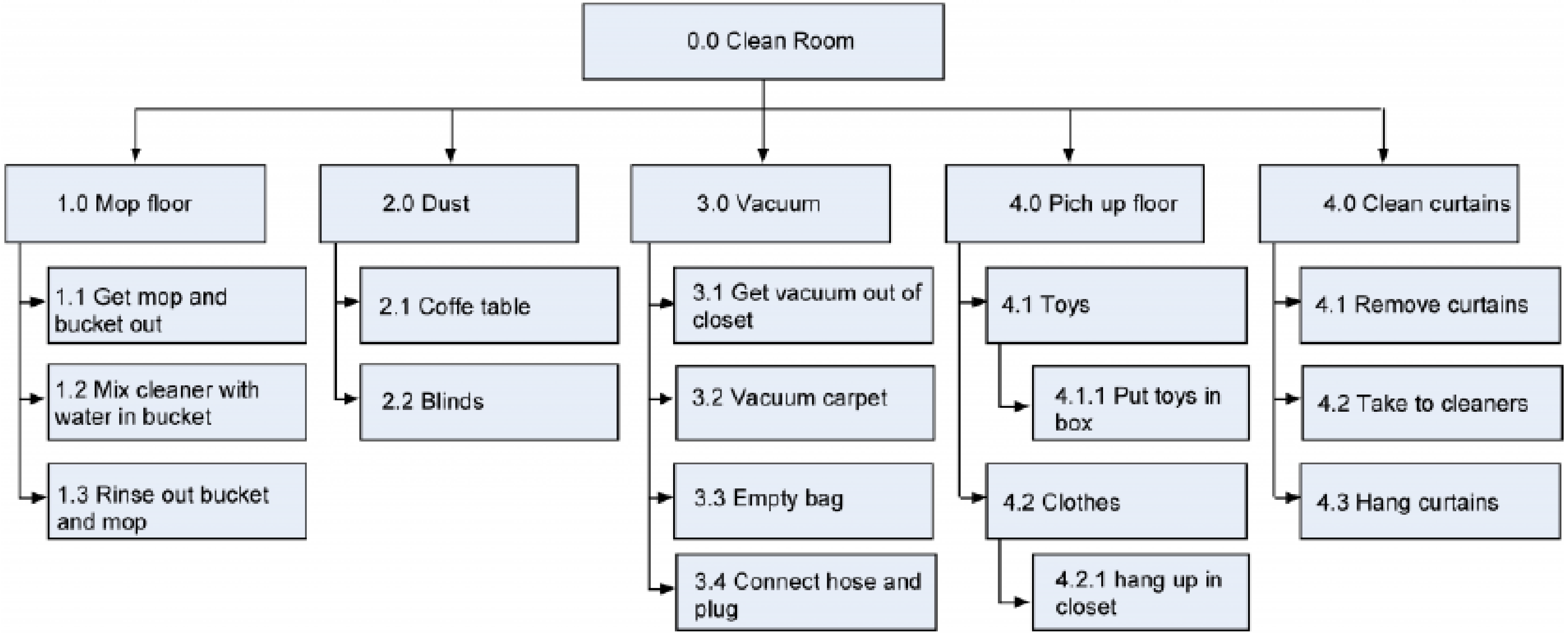
WBS

- **Work Breakdown Structure (WBS)**
  - A hierarchical decomposition (or a product-oriented family tree subdivision) of the total scope of work to be carried out
  - Complicated task → smaller tasks until they cannot be further subdivided
  - Reflects the way in which project costs and data will be summarized and reported
- **Scope creep**:
  - Additional scope or requirements are accepted without adjusting schedule, budget, or resource needs. To combat scope
  - Use a change control system where all changes are evaluated for the potential value they bring to the project and the potential resources, time, and budget needed to realize the potential value. To be presented to the project governance body, product owner, or executive sponsor for formal approval
- **Out of scope**: an element that is not contained in the WBS and not a part of the project

WBS example*

I want a clean room





WBS decomposition problems

At what level do you stop ?

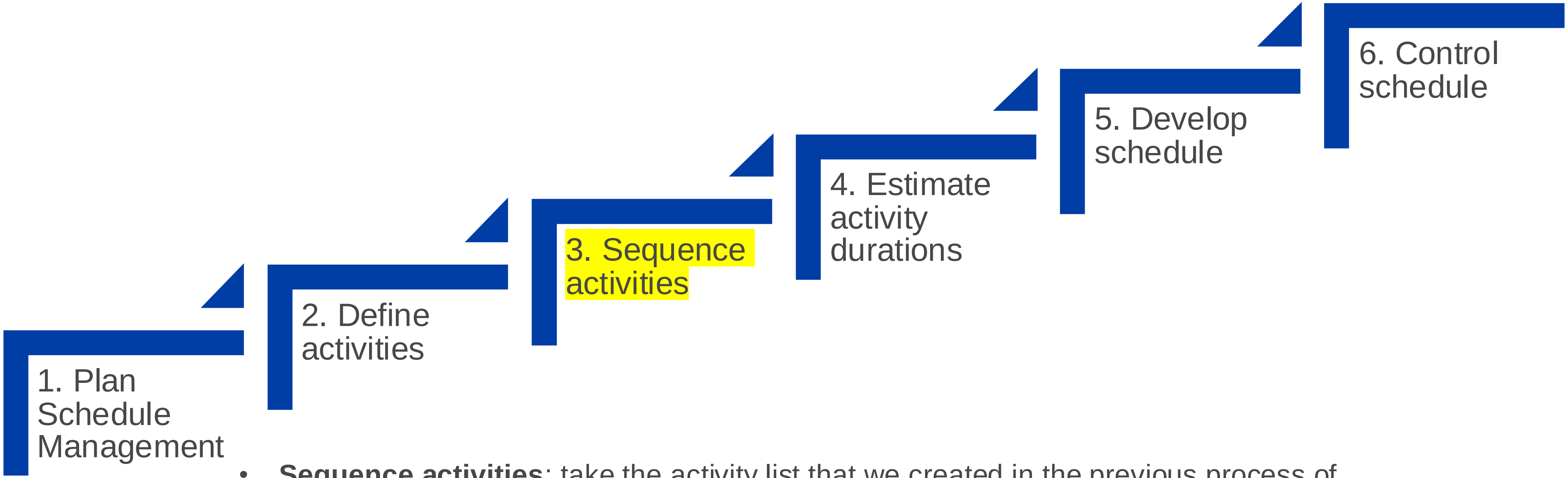
- Small work packages = accurate schedule and cost control
- Detailed WBS
  - Creation of of hundreds or even thousands of cost accounts and charge numbers
  - Interdependencies between activities can become so complex that meaningful networks cannot be constructed.

Rolling wave planning*

- Progressive elaboration that models project planning the way we see things in the real world
- Things “in the near future” vs. activities “in distant future”
- Popular in Agile

3. Sequence activities

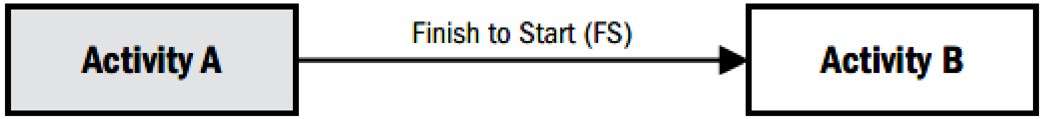
Sequence activities



- **Sequence activities**: take the activity list that we created in the previous process of Define Activities and arrange those activities in the order they must be performed.

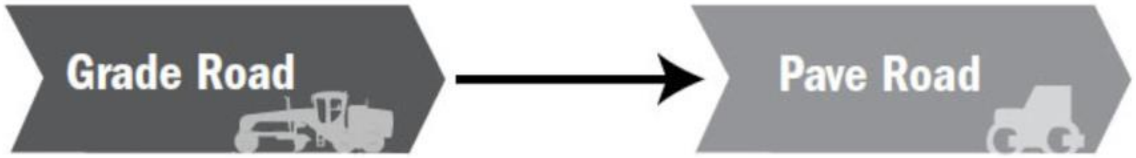
Dependency

Dependencies are those things that influence which activities must be performed first
.
To say that task B depends on task A means that task A produces a deliverable that is needed in order to do the work associated with task B.



- No predecessor
- Successor = B

- Predecessor = A
- No successor

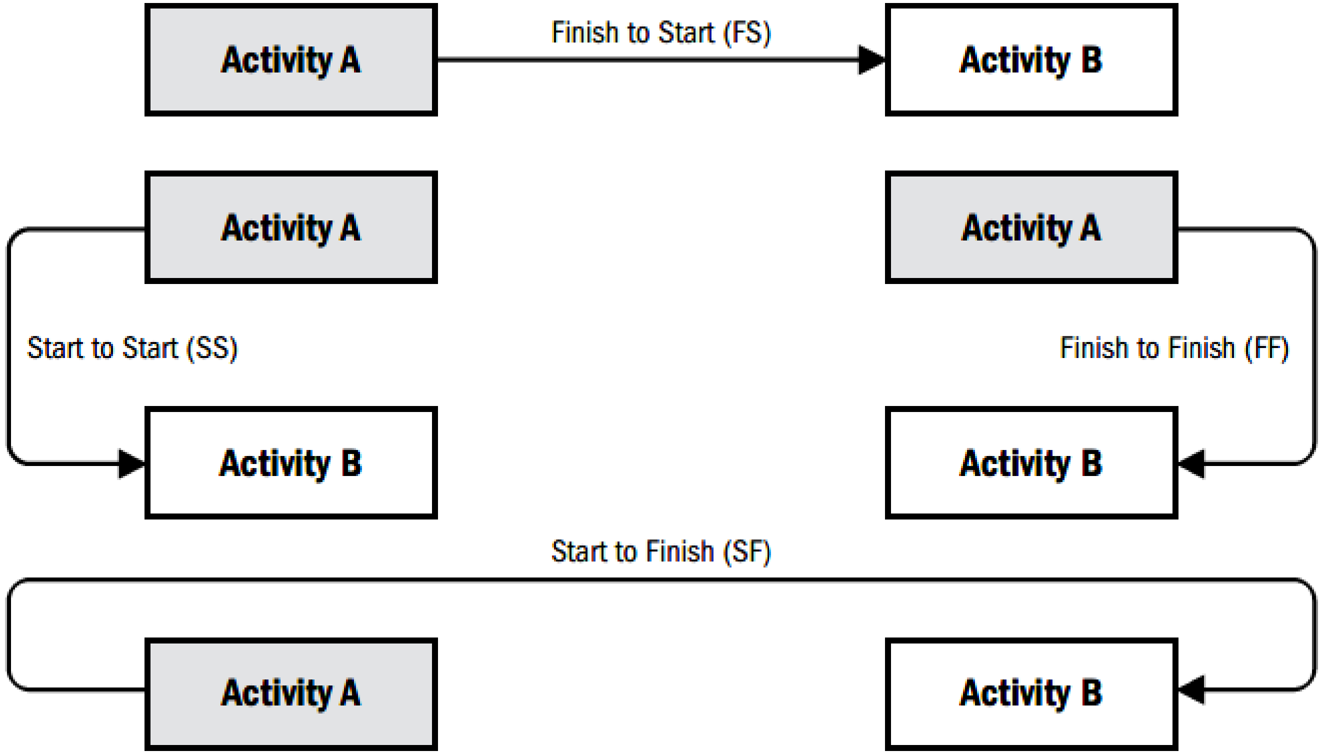


Two activities with a dependency, creating
a finish-to-start relationship

Types of dependencies* (1)

1) A must be complete before B can begin

2) B can start after A has started



4) A must be complete before B can finish (*or B cannot finish sooner than A*)

3) B cannot complete until A has started

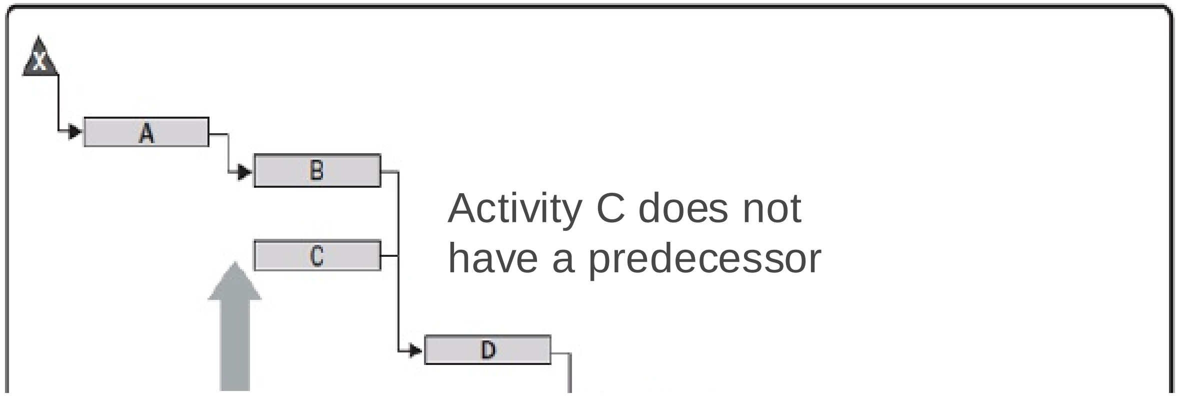
Exercise 1

1. “Once you have finished collecting the data (task A), you may begin entering the data (task B)”
2. “As soon as you begin collecting data (task A), you might begin entering the data (task B)”
3. “When the new system starts to work (task A), the old system can be discontinued (task B)”
4. “Data entry (task B) cannot finish until data collection (task A) has finished”
5. Hoist object with crane (task A), receive object and unload crane (task B)
6. Connect hospital to the grid (task A), disable generators (task B)
7. Paint room one (task A), Hang wallpaper in room tow (task B). you will have both a painter and a decorator available to paint and hang wallpaper at the same time; ensuring they are working alongside one another to guarantee a short project duration

Types of dependencies* (2)

- **Mandatory**: cannot be broken
- **Discretionary**: are not always true – usually result of best practises
- **External**: are outside of the project's control and scope
- **Internal**: those that the team can control

Defining activities attributes



- Each activity, excluding the initial start milestone : **?S relationship**
- Every activity, excluding the final finish milestone: **F? relationship**

- Dangling (or open) activity

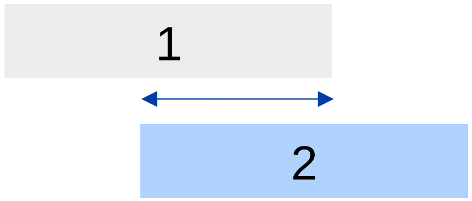
Type of constraints*

- **Technical constraints**: one task (the successor) requires output from another (the predecessor) before work can begin on it
- **Management constraints**
- **Interproject constraints**: deliverables from one project are needed by another project
- **Date constraints**
  - Impose start or finish dates on a task
  - Generally conflict with the schedule that is calculated and driven by the dependency relationship between the tasks
  - No earlier than
  - No later than
  - On this date

Leads & Lags*

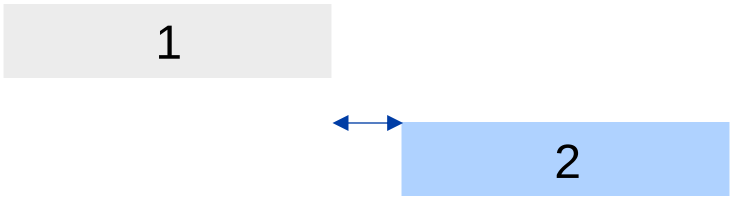
- **Leads/lags** = “accelerations” or delays between tasks
- **Lead**: amount of time a successor activity can be advanced with respect to a predecessor activity. Allows an “acceleration” of the successor activity
- **Lag**: amount of time a successor activity will be delayed with respect to a predecessor activity. Imposes a delay of the successor activity. Introduce risk, especially in JIT (just in time) inventory management
- The use of leads and lags should not replace schedule logic

Coding might be able to start 5 days before the design is finished



Lead

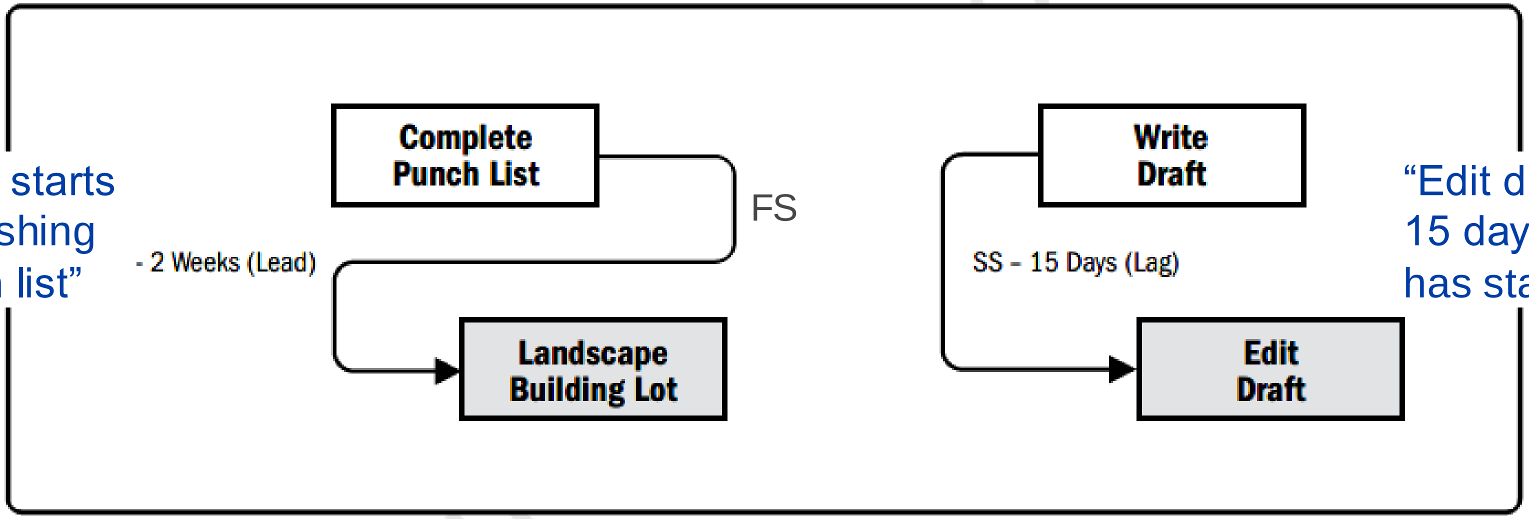
You must wait 3 days after pouring concrete before you can construct the frame of the house



Lag

Leads & Lags - Example

“Landscaping work” starts 2 weeks prior to finishing of “Complete Punch list”

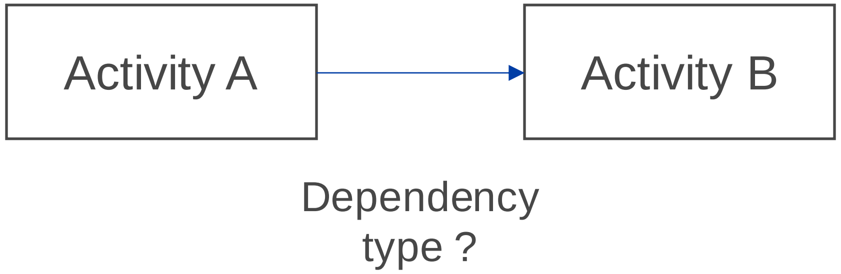


“Edit draft” can only start 15 days after “Write Draft” has started

Exercise 2

The data is being collected by mailing out a survey and is entered as the surveys are returned. You wait 10 days from the date you mail the surveys until you schedule entering the data from the surveys

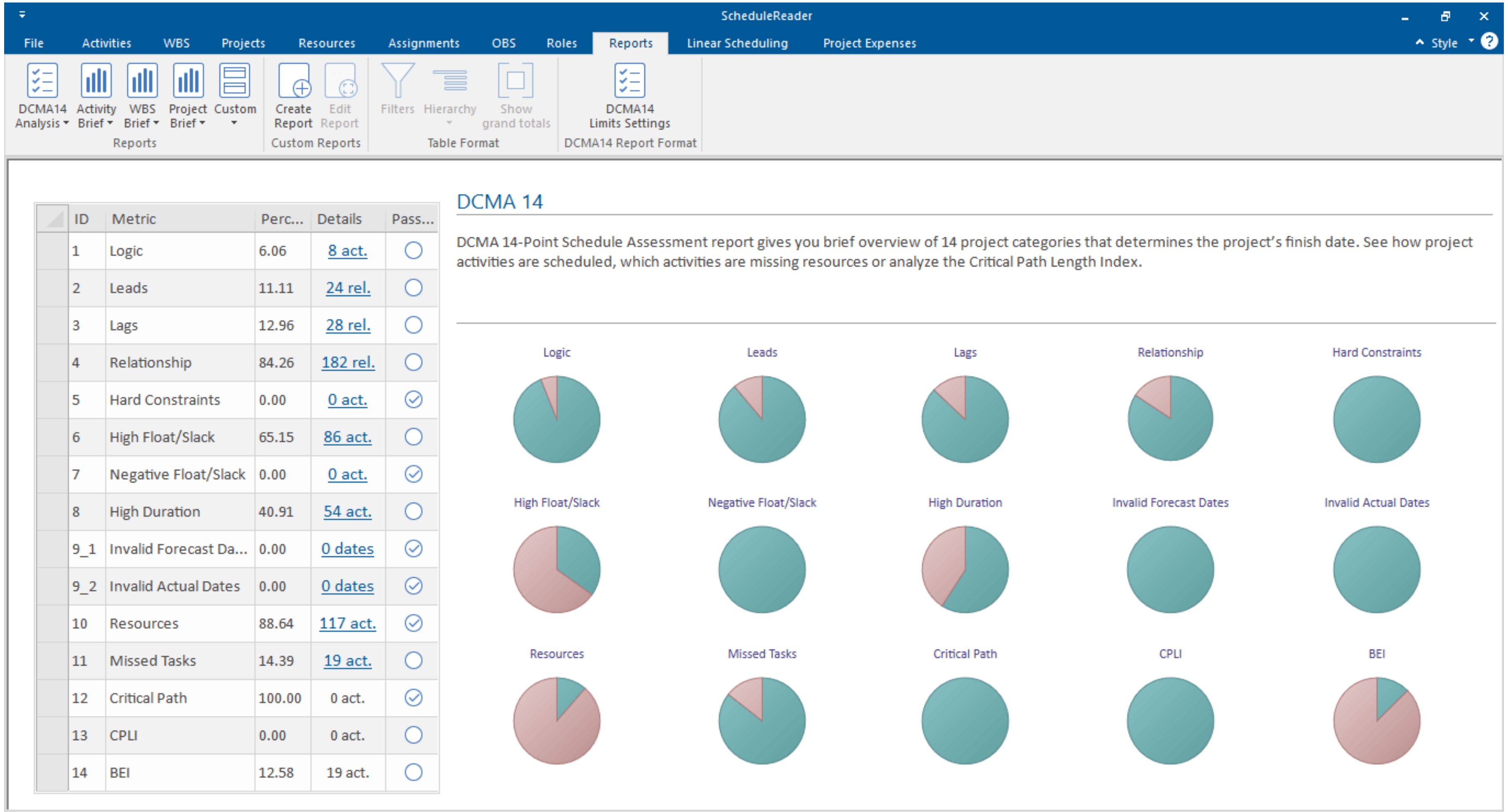
- Task A = mailing the survey
- Task B = data entry



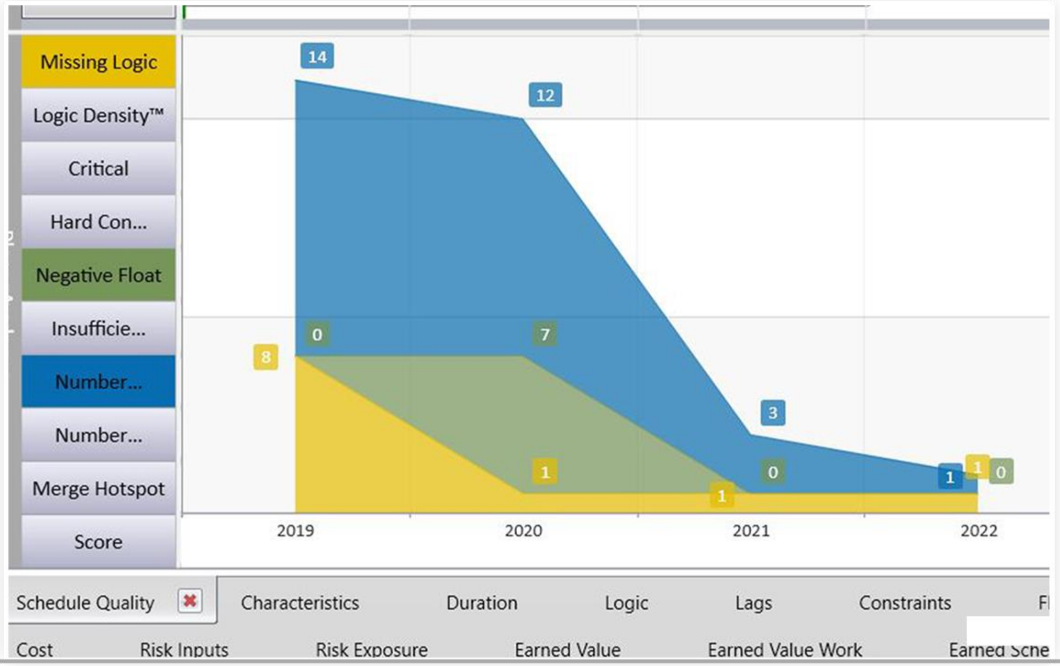
Schedule Quality Metrics

- Schedule metrics – examples
  - Missing logic
  - Logic density ($2 < x < 4$)
  - Hard contraints (e.g. predetermined start or finish dates)
  - Negative float
  - Number of lags
  - Number of leads
  - Merge hotspots
- Industry standards – examples
  - NASA Schedule Management Handbook: https://www.nasa.gov/pdf/420297main_NASA-SP-2010-3403.pdf
  - The United States Government Accountability Office (GAO): GAO Schedule Assessment Guide

Software Example - ScheduleReader

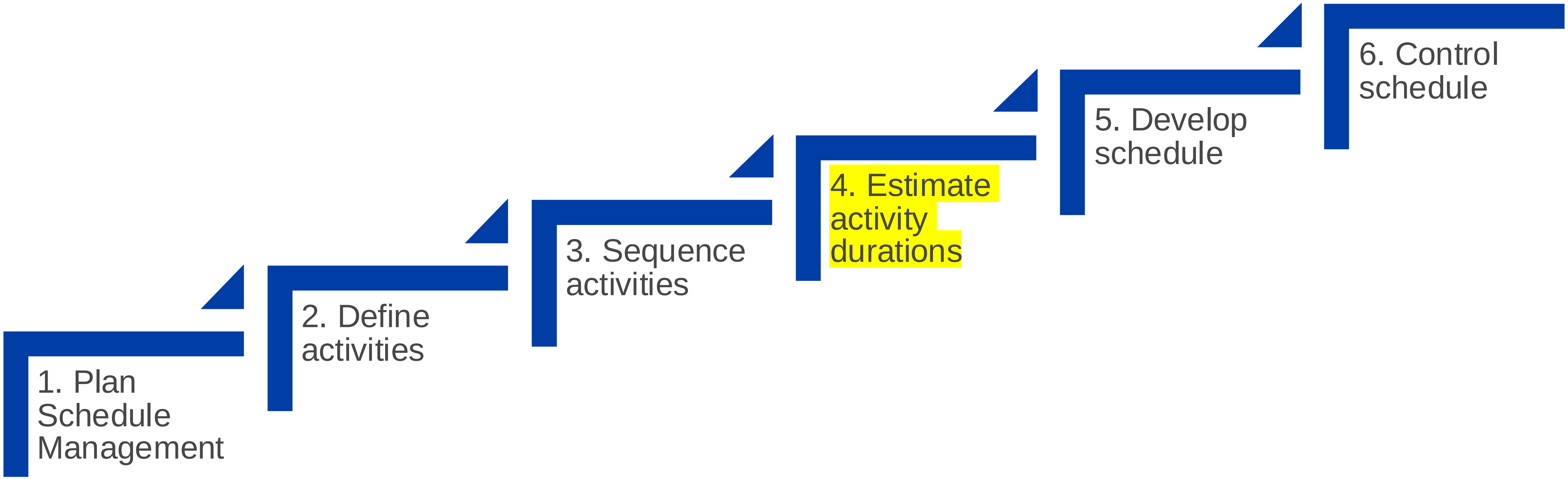


Software Example - Acumen Fuse



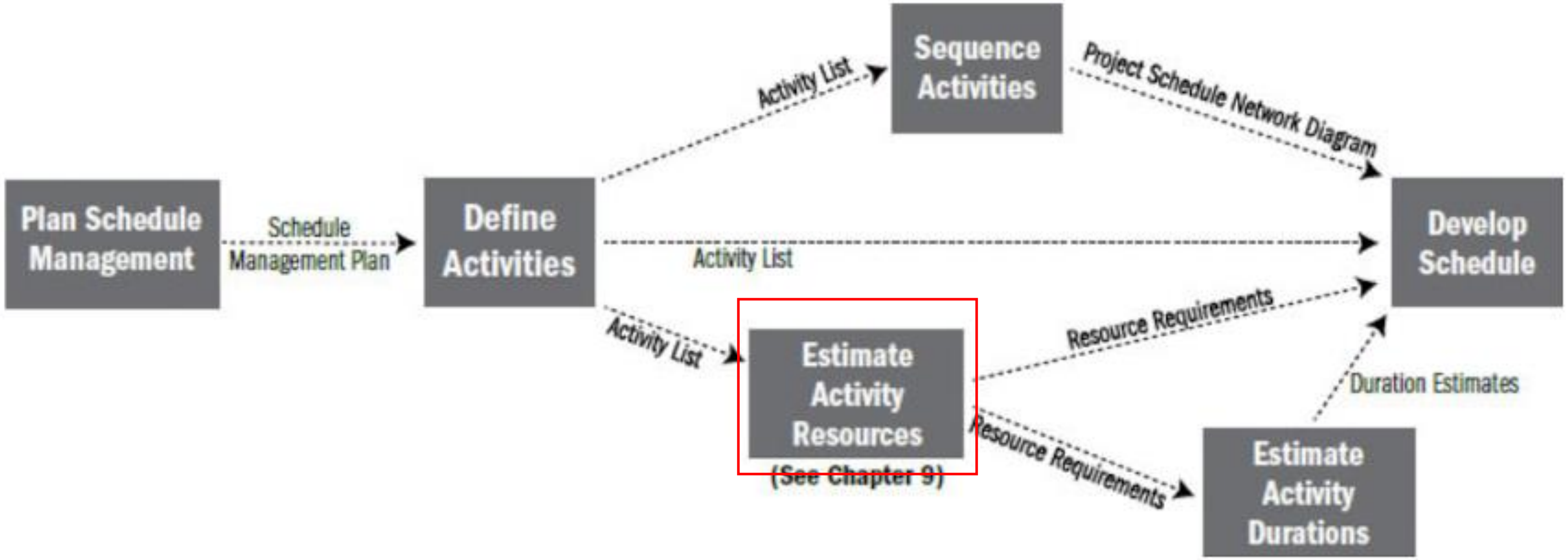
4. Estimate activity durations

Estimating activity durations



- **Estimating activity durations**: Each activity in the activity list is analyzed to estimate how long it will take.
- Duration of activity depends on many factors

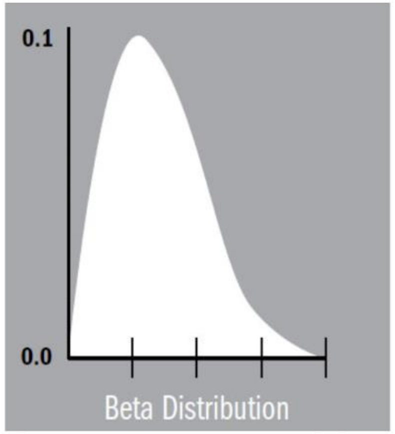
Estimate activities resources

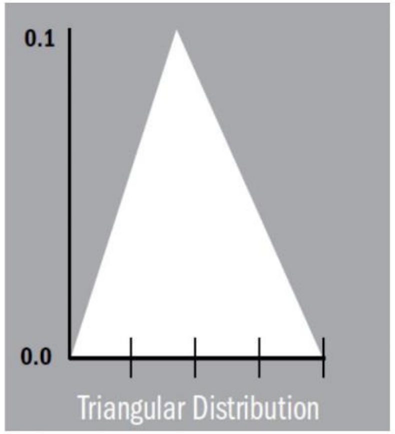


- Factors that determine the duration of an activity
  - who will be doing the work
  - when they are available
  - how many resources will be assigned to this activity
  - amount of work contained in the activity.

Estimating activity durations*

1. **Analogous estimating**: uses values, or attributes, of a previous project that are similar to the current project.
2. **Parametric estimating**: uses a statistical relationship between relevant historical data and other variables
3. **Bottom-up estimating**: The work within the activity is decomposed into more detail. These estimates are then aggregated into a total quantity for each of the activity's durations
4. **3-point estimating**
    - Helps define an approximate range for an activity's duration
    - Triangular distribution … (optimistic + most likely + pessimistic) / 3
    - Beta distribution … (optimistic + most likely + pessimistic) / 6



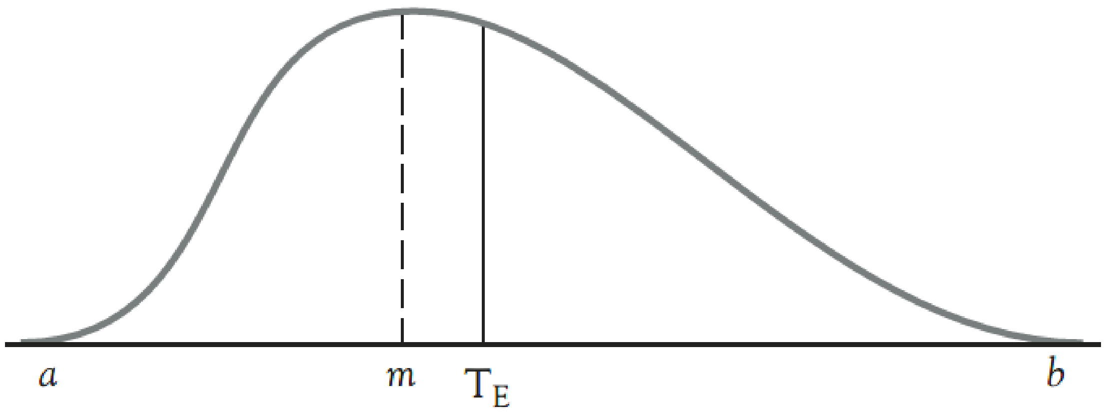


Three-point estimate – beta distribution*

Also called PERT

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

t_e = expected time
a = most optimistic time
b = most pessimistic time
m = most likely time.



Three-point estimate – beta distribution*

$$Standard\ deviation\ (activity) = \sigma_{t_e} = \frac{b-a}{6}$$

$$Variance\ (activity) = {\sigma_{t_e}}^2$$

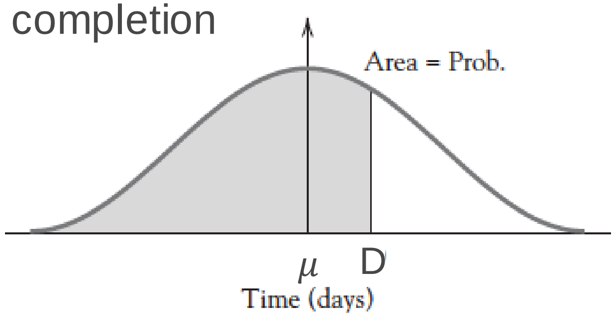
$$Standard\ deviation\ (path) = \sigma_{path} = \sqrt{\sigma_1^2 + \sigma_2^2 + \cdots + \sigma_N^2}$$ (assumes statistical indipendence!!)

$$Variance\ (path) = \sum Variance(activity)$$

$$Project\ Expected\ critical\ time = \sum t_e = \mu$$

Probability of completing the project on time*

Frequency distribution of the path completion



$$z = (D - \mu) / \sqrt{\sigma_\mu^2}$$

where:

D = the desired project completion time.

μ = the sum of the T_E activities on the path being investigated.

σ_μ^2 = the variance of the path being considered (the sum of the variances of the activities on the path).

- Z = number of standard deviations separating D and μ
- To complete a project by a specified time require that all the paths in the project's network be completed by the specified time
- Assuming that the paths are independents of one another, the probability that the entire project will be on time can be calculated by multiplying these probabilities together
- Excel: Probability =NORM.DIST(D,μ,σ,TRUE)
- Excel: D=NORM.INV(P,μ,σ)

Exercise 3

Activity	Optimistic Time (a)	Most Likely (m)	Pessimistic Time (b)
A	3	4	5
B	4	4.5	8
C	4	6	8

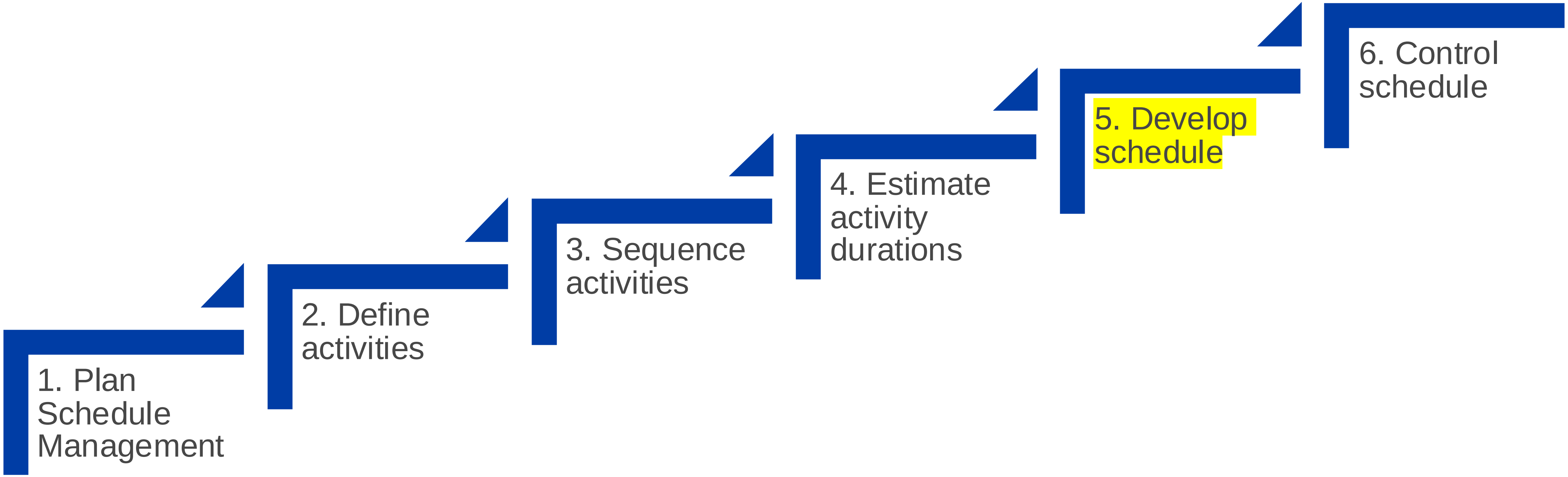
- Assume all 3 activities are on the critical path
- Use 3-point estimating for activity duration (beta distribution)
- Calculate the project expected critical time, variance and standard deviation
- What is the probability of completing the project within 16, 17, 14 & 13 weeks?

Exercise 3 - Solution

	optimistic (a)	most likely (m)	pessimistic (b)	Te	Std dev	Var
A	3	4	5	4	0.333333	0.111111
B	4	4.5	8	5	0.666667	0.444444
C	4	6	8	6	0.666667	0.444444
			μ (path)	15		
			Var (path)			1
			Std dev (path)		1	
	D	z	Prob			
P(<16)	16	1.0	**84.1%**			
P(<17)	17	2.0	**97.7%**			
P(<14)	14	-1.0	**15.9%**			
P(<13)	13	-2.0	**2.3%**			

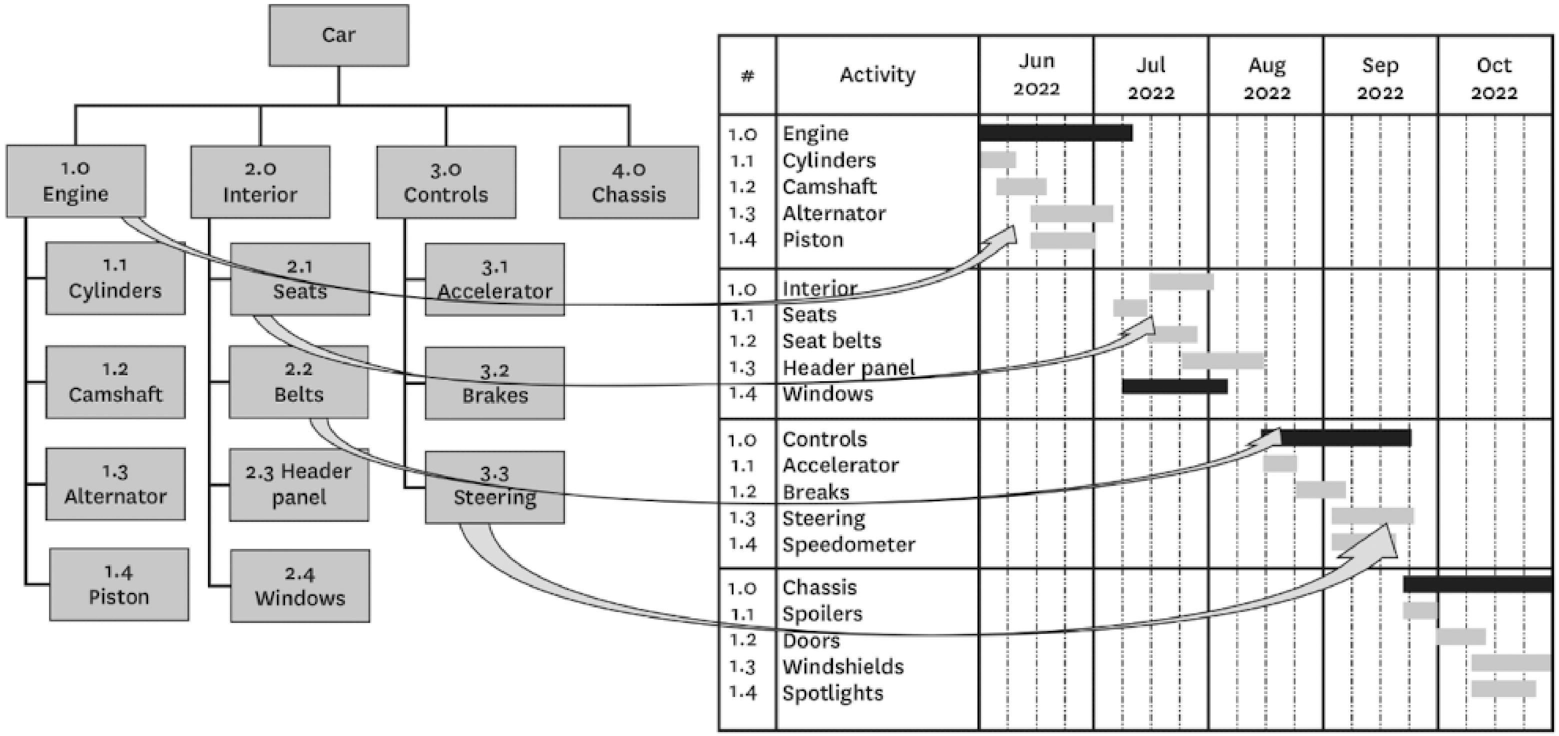
5. Develop schedule

Develop schedule



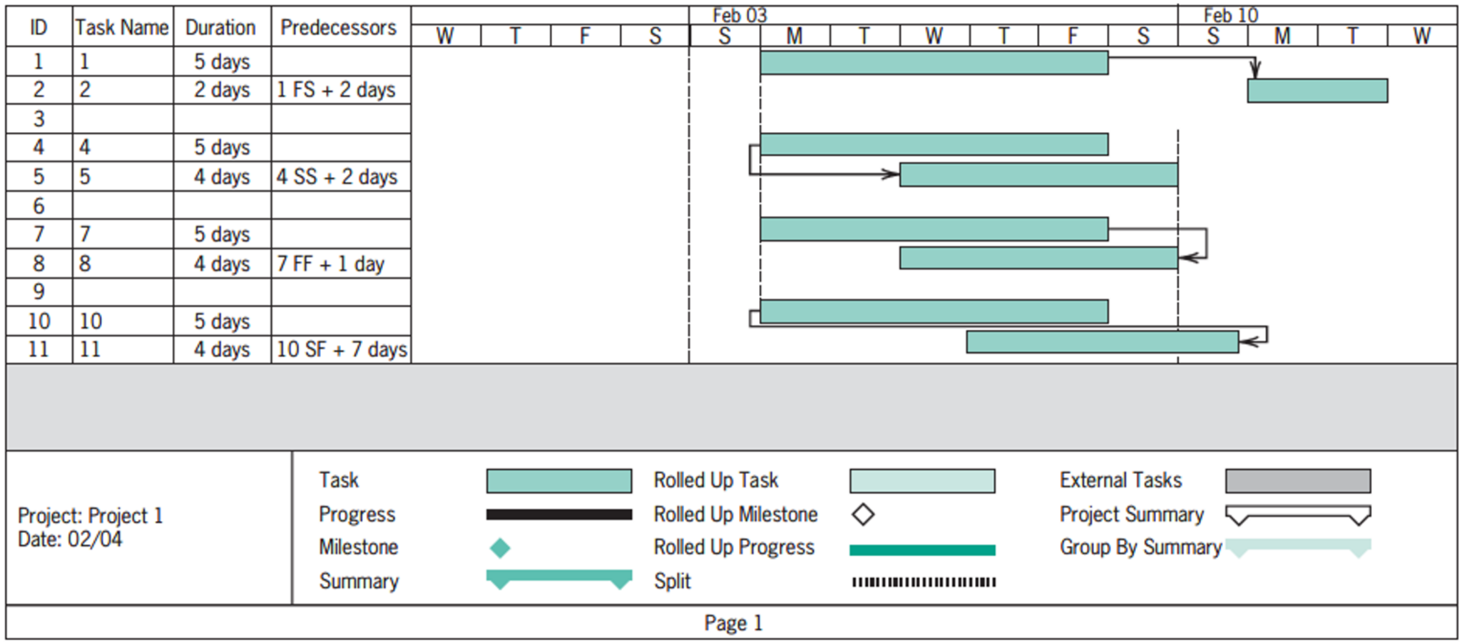
- **Develop schedule**: process of analyzing activity sequences, durations, resource requirements, and schedule constraints to create a schedule model for project execution and monitoring and controlling

Schedule creation

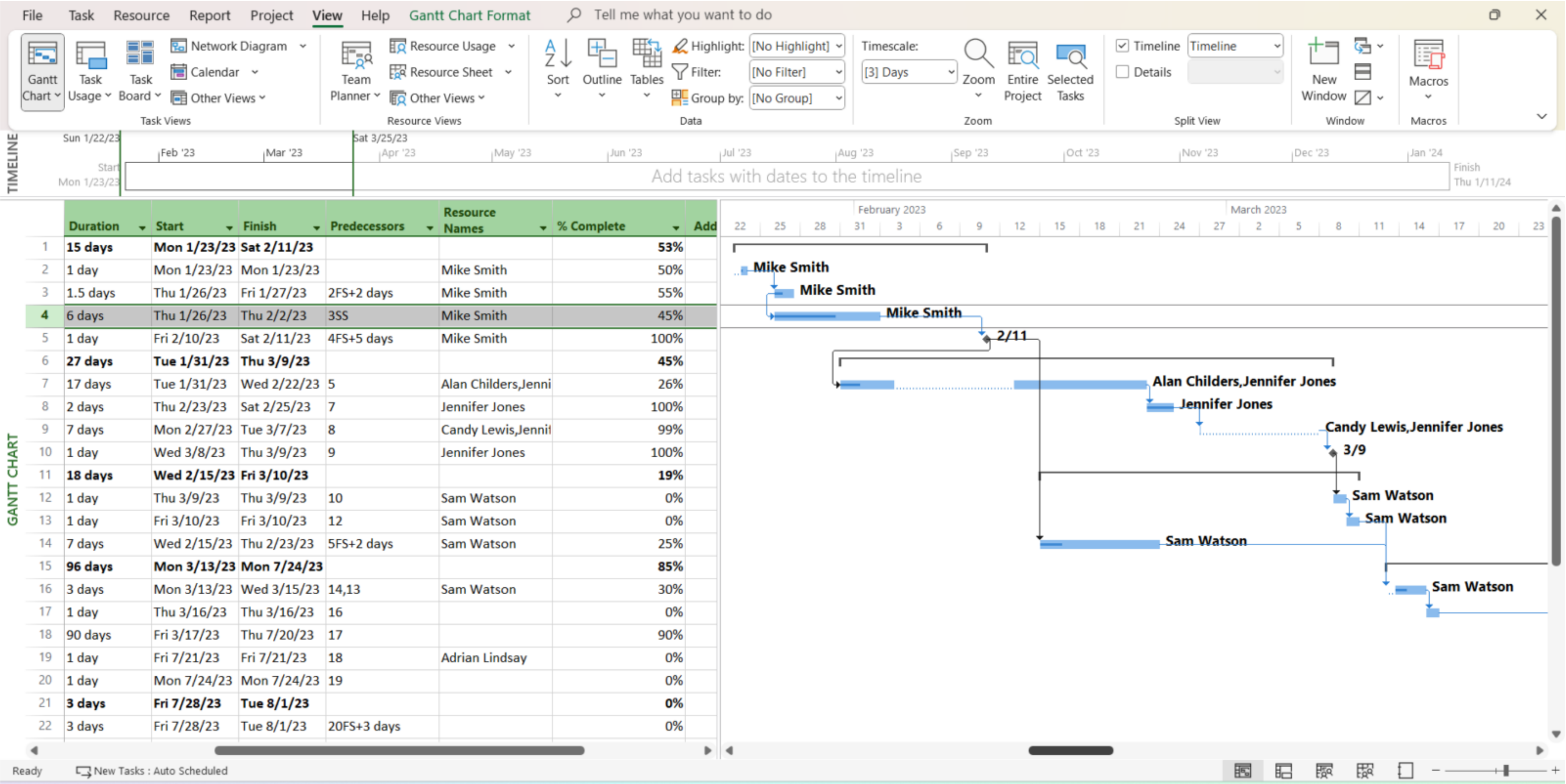


Bar charts (or Gantt Chart)

- Show activities represented as horizontal bars and typically have a calendar along the horizontal axis.
- The length of the bar corresponds to the length of time the activity should require.

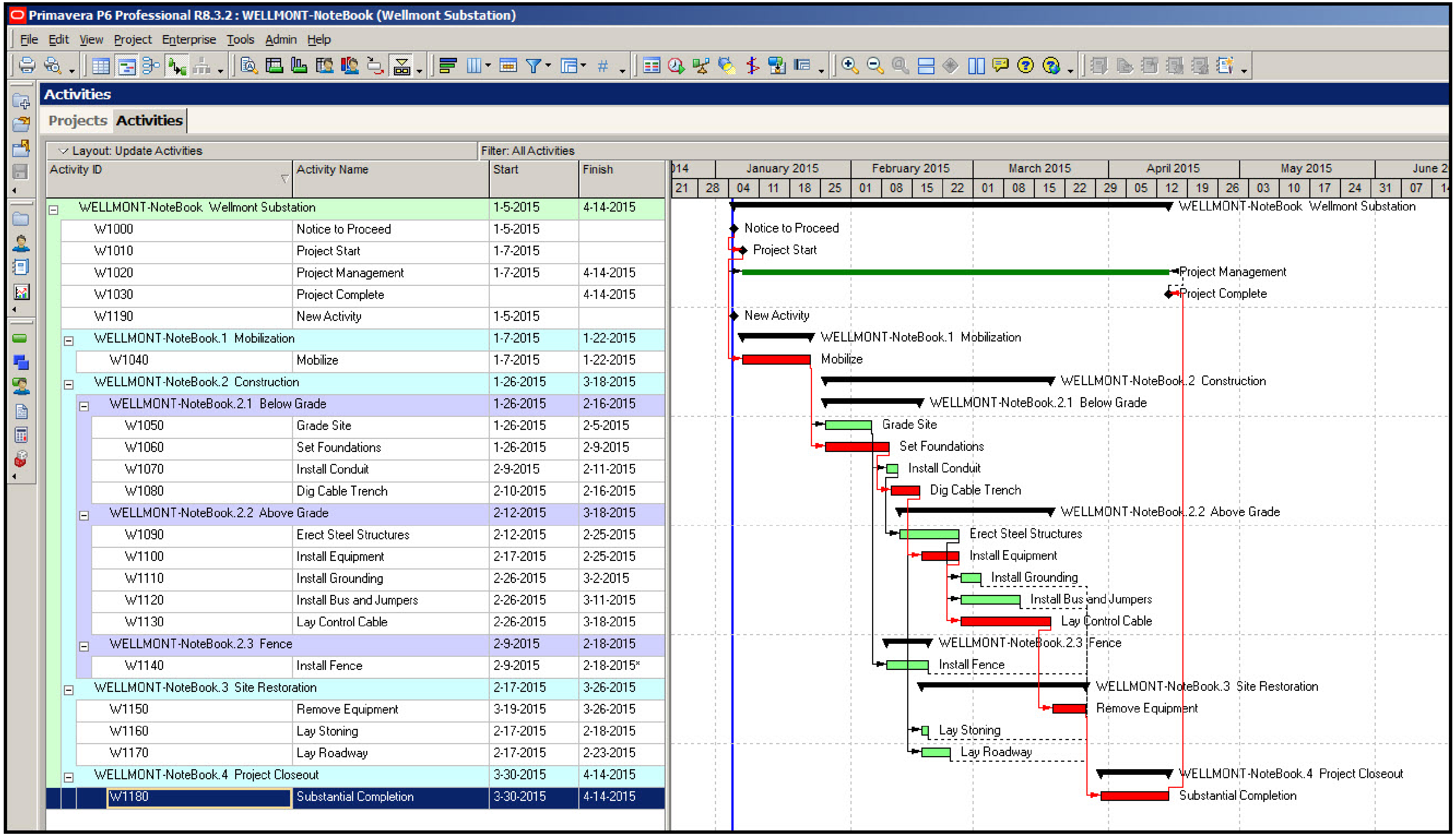


Gantt Chart – MS Project Example



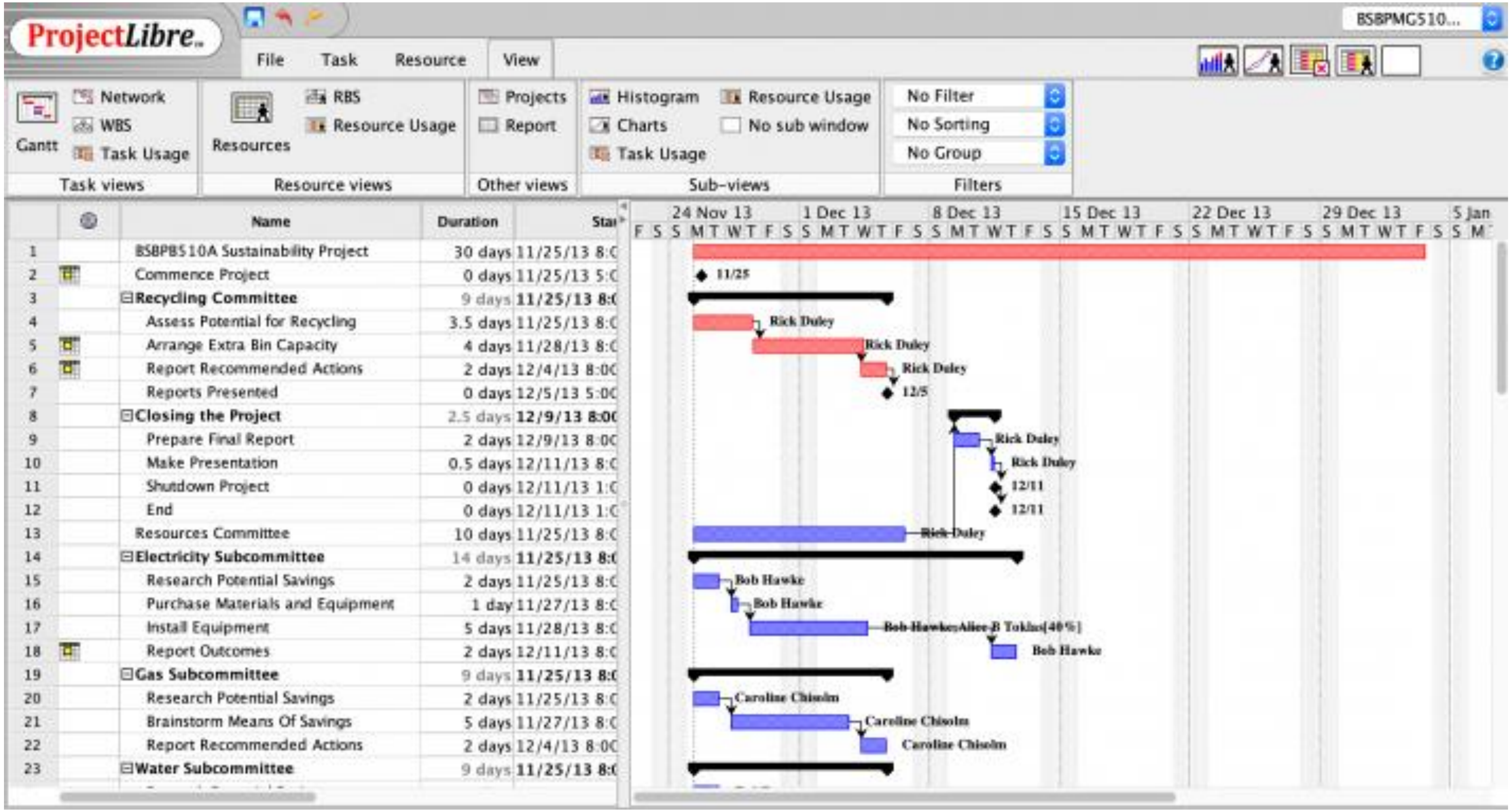
	Duration	Start	Finish	Predecessors	Resource Names	% Complete
1	**15 days**	**Mon 1/23/23**	**Sat 2/11/23**			**53%**
2	1 day	Mon 1/23/23	Mon 1/23/23		Mike Smith	50%
3	1.5 days	Thu 1/26/23	Fri 1/27/23	2FS+2 days	Mike Smith	55%
4	6 days	Thu 1/26/23	Thu 2/2/23	3SS	Mike Smith	45%
5	1 day	Fri 2/10/23	Sat 2/11/23	4FS+5 days	Mike Smith	100%
6	**27 days**	**Tue 1/31/23**	**Thu 3/9/23**			**45%**
7	17 days	Tue 1/31/23	Wed 2/22/23	5	Alan Childers,Jenni	26%
8	2 days	Thu 2/23/23	Sat 2/25/23	7	Jennifer Jones	100%
9	7 days	Mon 2/27/23	Tue 3/7/23	8	Candy Lewis,Jennif	99%
10	1 day	Wed 3/8/23	Thu 3/9/23	9	Jennifer Jones	100%
11	**18 days**	**Wed 2/15/23**	**Fri 3/10/23**			**19%**
12	1 day	Thu 3/9/23	Thu 3/9/23	10	Sam Watson	0%
13	1 day	Fri 3/10/23	Fri 3/10/23	12	Sam Watson	0%
14	7 days	Wed 2/15/23	Thu 2/23/23	5FS+2 days	Sam Watson	25%
15	**96 days**	**Mon 3/13/23**	**Mon 7/24/23**			**85%**
16	3 days	Mon 3/13/23	Wed 3/15/23	14,13	Sam Watson	30%
17	1 day	Thu 3/16/23	Thu 3/16/23	16		0%
18	90 days	Fri 3/17/23	Thu 7/20/23	17		90%
19	1 day	Fri 7/21/23	Fri 7/21/23	18	Adrian Lindsay	0%
20	1 day	Mon 7/24/23	Mon 7/24/23	19		0%
21	**3 days**	**Fri 7/28/23**	**Tue 8/1/23**			**0%**
22	3 days	Fri 7/28/23	Tue 8/1/23	20FS+3 days		0%

Gantt Chart – Primavera P6 example



Activity ID	Activity Name	Start	Finish
WELLMONT-NoteBook Wellmont Substation		1-5-2015	4-14-2015
W1000	Notice to Proceed	1-5-2015	
W1010	Project Start	1-7-2015	
W1020	Project Management	1-7-2015	4-14-2015
W1030	Project Complete		4-14-2015
W1190	New Activity	1-5-2015	
WELLMONT-NoteBook.1 Mobilization		1-7-2015	1-22-2015
W1040	Mobilize	1-7-2015	1-22-2015
WELLMONT-NoteBook.2 Construction		1-26-2015	3-18-2015
WELLMONT-NoteBook.2.1 Below Grade		1-26-2015	2-16-2015
W1050	Grade Site	1-26-2015	2-5-2015
W1060	Set Foundations	1-26-2015	2-9-2015
W1070	Install Conduit	2-9-2015	2-11-2015
W1080	Dig Cable Trench	2-10-2015	2-16-2015
WELLMONT-NoteBook.2.2 Above Grade		2-12-2015	3-18-2015
W1090	Erect Steel Structures	2-12-2015	2-25-2015
W1100	Install Equipment	2-17-2015	2-25-2015
W1110	Install Grounding	2-26-2015	3-2-2015
W1120	Install Bus and Jumpers	2-26-2015	3-11-2015
W1130	Lay Control Cable	2-26-2015	3-18-2015
WELLMONT-NoteBook.2.3 Fence		2-9-2015	2-18-2015
W1140	Install Fence	2-9-2015	2-18-2015*
WELLMONT-NoteBook.3 Site Restoration		2-17-2015	3-26-2015
W1150	Remove Equipment	3-19-2015	3-26-2015
W1160	Lay Stoning	2-17-2015	2-18-2015
W1170	Lay Roadway	2-17-2015	2-23-2015
WELLMONT-NoteBook.4 Project Closeout		3-30-2015	4-14-2015
W1180	Substantial Completion	3-30-2015	4-14-2015

Gantt Chart – Project Libre (Open Source)



Project schedule network diagrams

AON (activity on node)

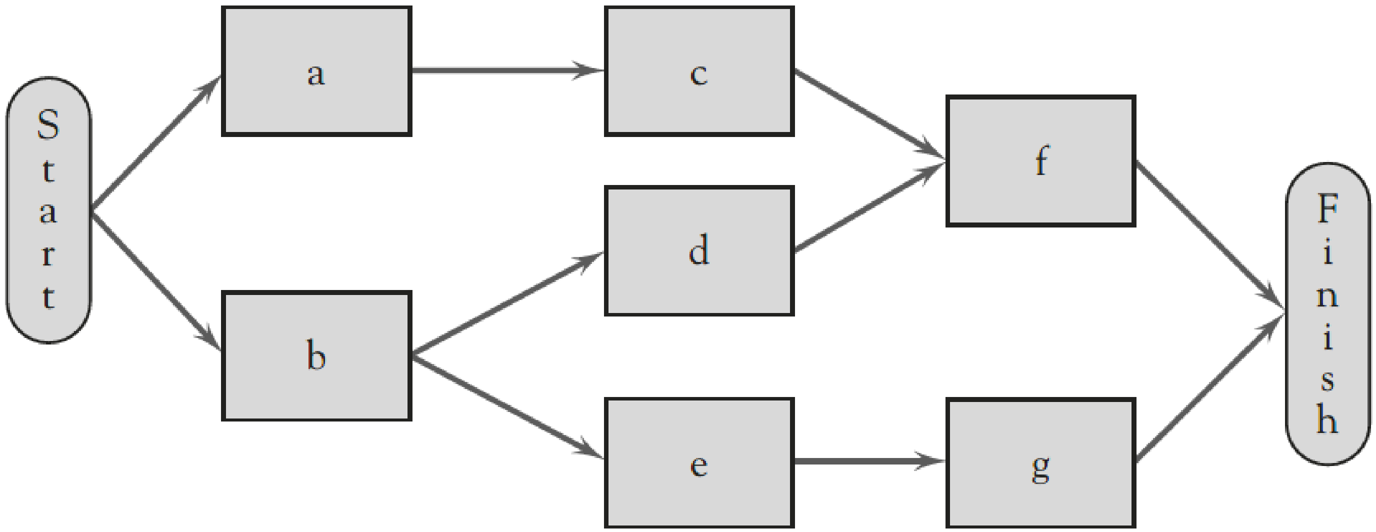
- Activities = nodes (rectangles)
- Arrows link the nodes to show their relationship
- Easy to draw, does not show events
- Can use FS, FF, SS, SF
- Most commonly used

AOA (activity on arrow)

- Activites = arrows
- Events = nodes (circles)
- More difficult to draw, depicts the relationship of the activities quite well
- Does not allow for leads/lags
- Can use dummy activities

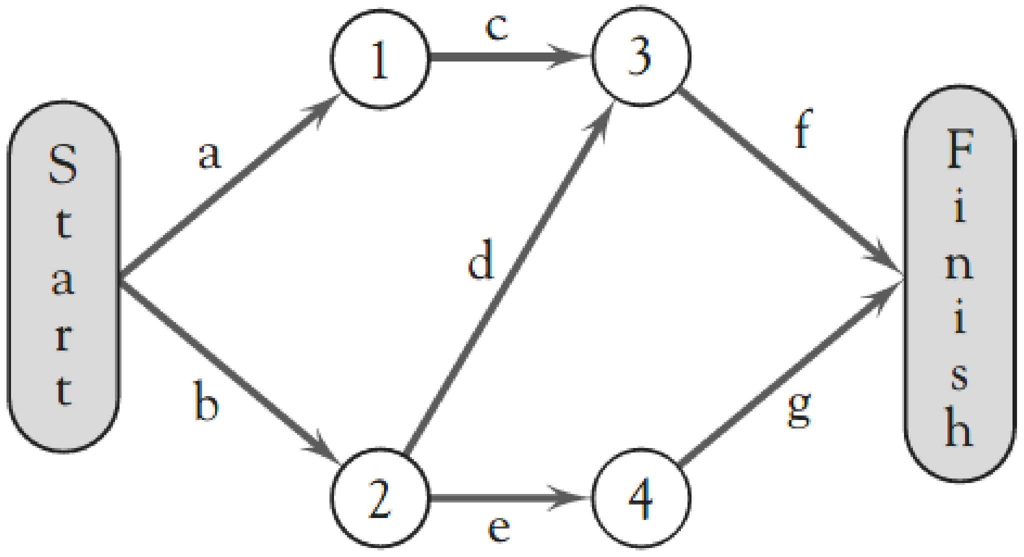
AON - example

Task	*Predecessor*
a	—
b	—
c	a
d	b
e	b
f	c, d
g	e

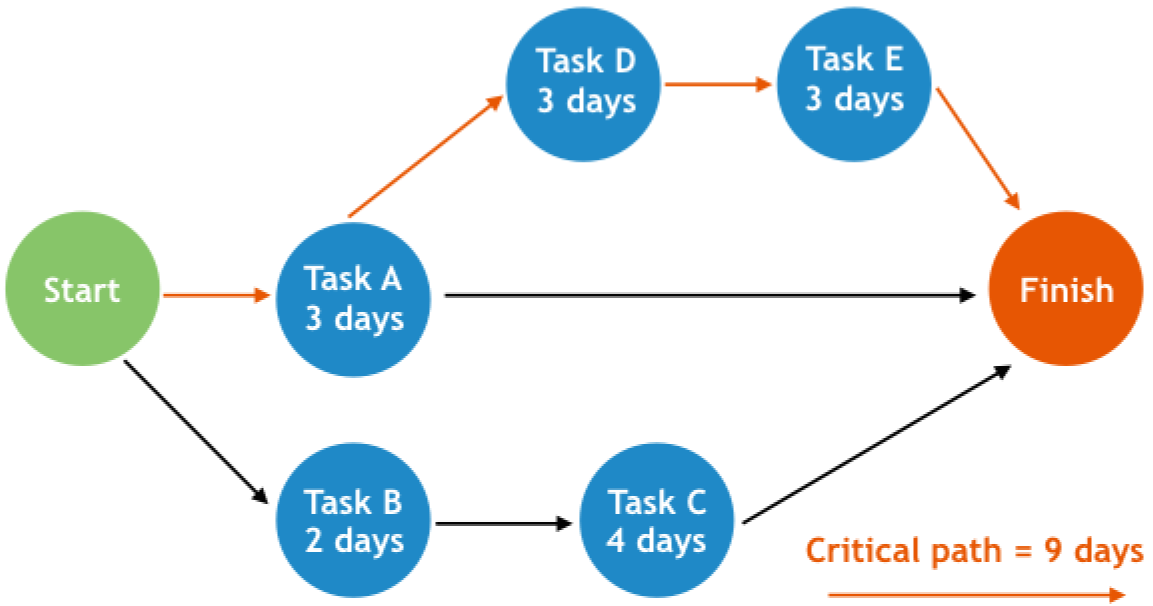


AOA - example

Task	*Predecessor*
a	—
b	—
c	a
d	b
e	b
f	c, d
g	e



Critical path method introduction

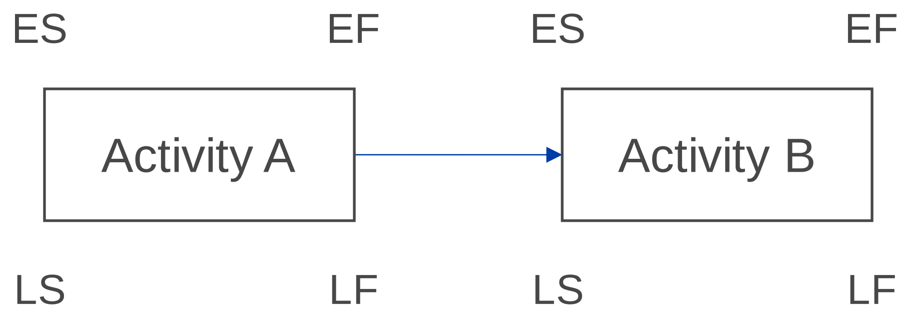


- Path 1: A → 3 days
- Path 2: A,D,E → 9 days
- Path 3: B,C → 6 days

- **Critical path**
  - The string of activities that determine the duration of the project
  - The longest path through the project

Critical path method calculation

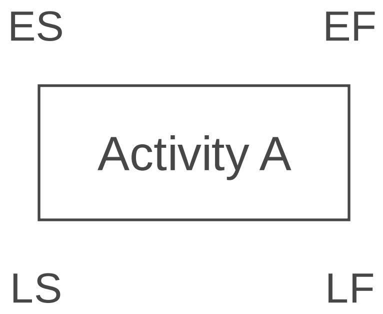
Definitions



- **Early Start (ES)** = earliest date an activity can possibly begin,
- **Early finish (EF)** = earliest date an activity can possibly finish
  - EF=ES + activity duration
- **Late start (LS)** = latest time the activity can begin
  - LS=LF – activity duration
- **Late finish (LF)** = latest time the activity can finish

Critical path method - Steps

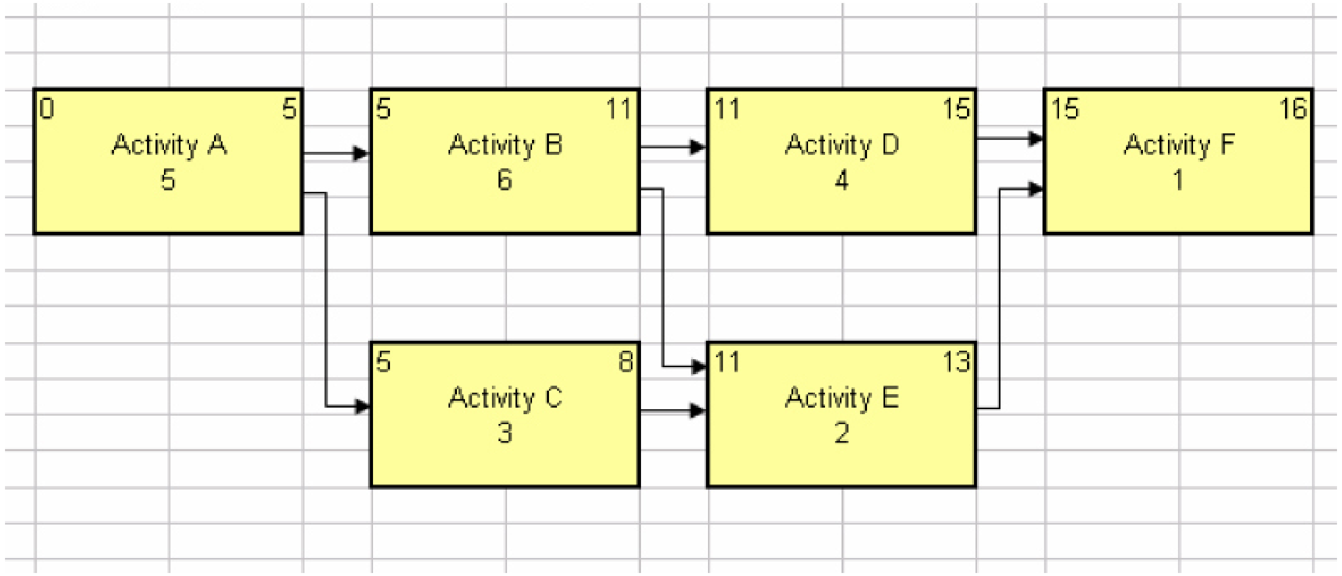
1. Calculate ES and EF
2. Calculate LS and LF
3. Calculate Total Float (TF)
4. Identify critical path



Critical path method calculation

Step 1

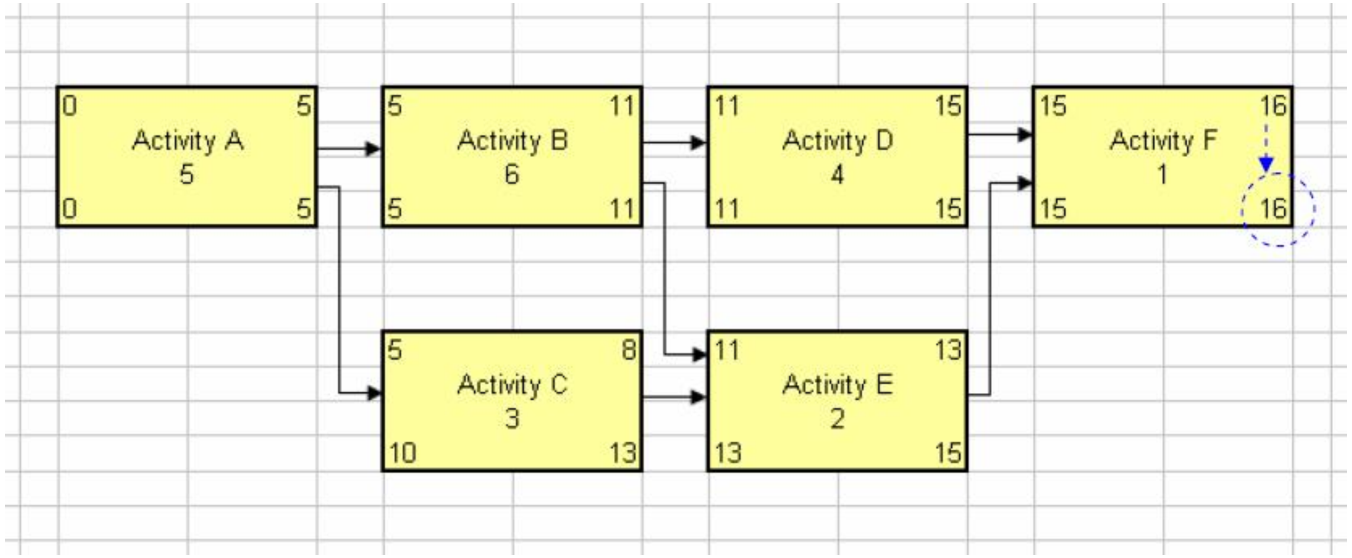
- **Forward pass**
  - <u>Objective</u>: calculate ES, EF for each activity and the overall project duration
  - The calculation process begins with placing a zero in the Early Start (ES) position of the first activity
  - EF = ES + duration
  - ES = maximum of EF value from immediate predecessors



Critical path method calculation

Step 2

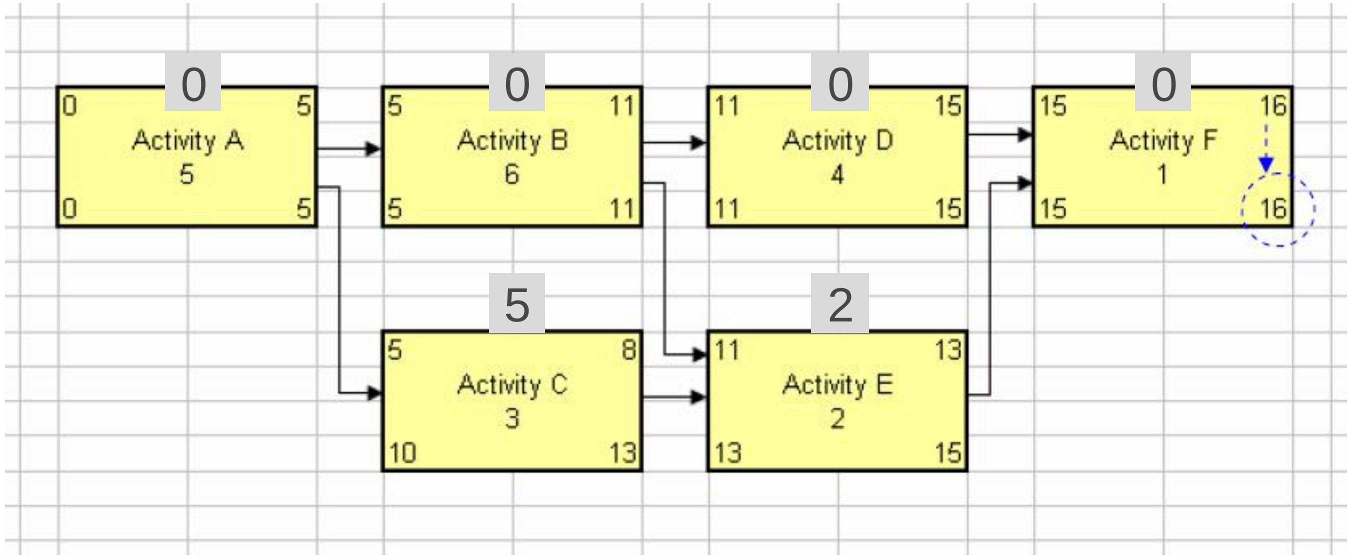
- **Backward pass**
  - Objective: Calculate LS and LF for each activity
  - Calculation step starts at the last activity in the schedule and proceeds backward through the schedule
  - EF value in the last activity is dropped down to the LF value
  - LS = LF - duration
  - LF = min LS value from immediate successor(s)



Critical path method calculation

Step 3 and 4

- **Step3: Calculate Total Float**
  - Total float = LF-EF or LS-ES
  - Float = amount of time a task can be delayed without delaying the project
- **Step 4: Determine Critical path**
  - Activities on the critical path have no float



Critical path method - Steps

1. Calculate ES and EF

- Forward pass
- ES(1^{st} activity)=0
- EF = ES + duration
- ES=max(EF pred)

2. Calculate LS and LF

- Backward pass
- LF(last act)=EF(last act)
- LS = LF – duration
- LF=min(LS succ)

3. Calculate Total Float (TF)

- Total float (TF) = LF-EF = LS-ES

4. Identify critical path

- All activities with TF=0

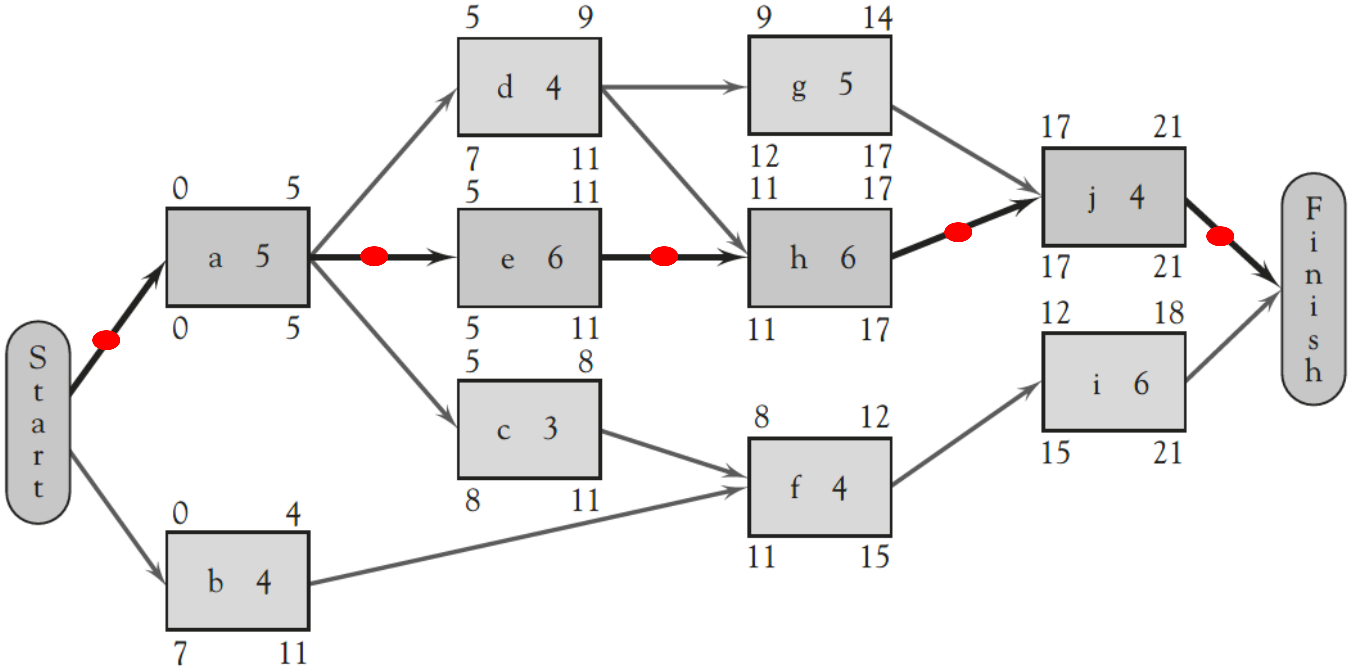
ES		EF
	Activity A	
LS		LF

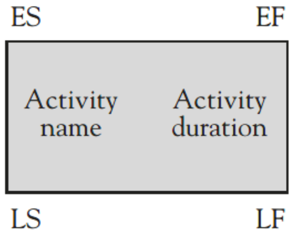
Exercise 4*

Activity	Predecessor	Duration
a	—	5 days
b	—	4
c	a	3
d	a	4
e	a	6
f	b, c	4
g	d	5
h	d, e	6
i	f	6
j	g, h	4

1. Draw the AON network
2. Calculate
   - ES, EF, LS, LF
3. Determine the critical path

Exercise - solution

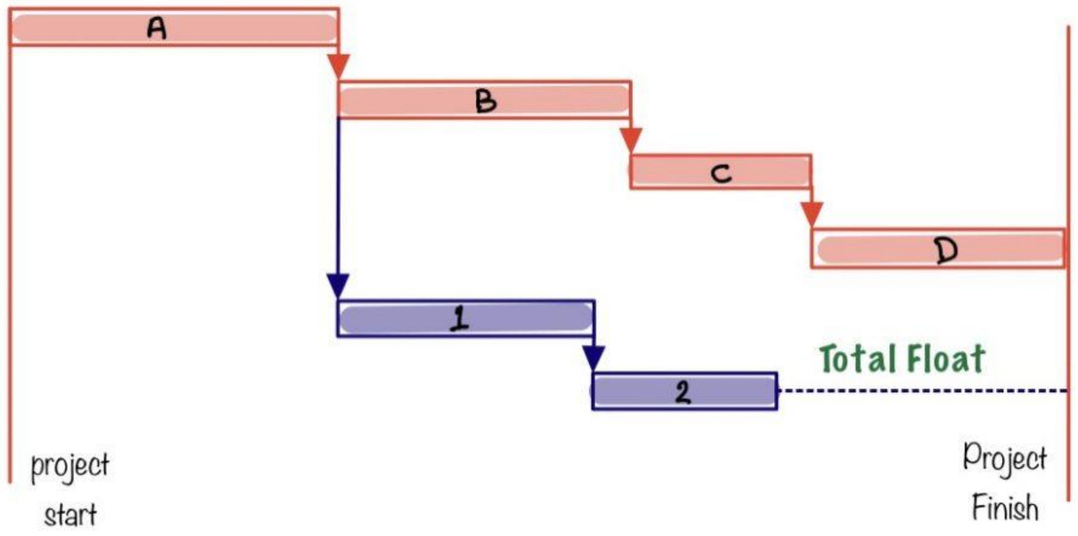


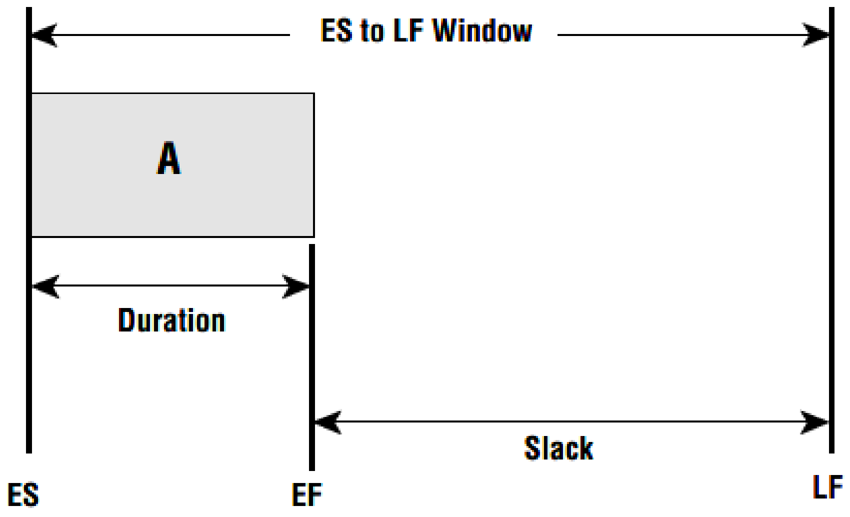


ES—Earliest start time
EF—Earliest finish time
LS—Latest start time
LF—Latest finish time

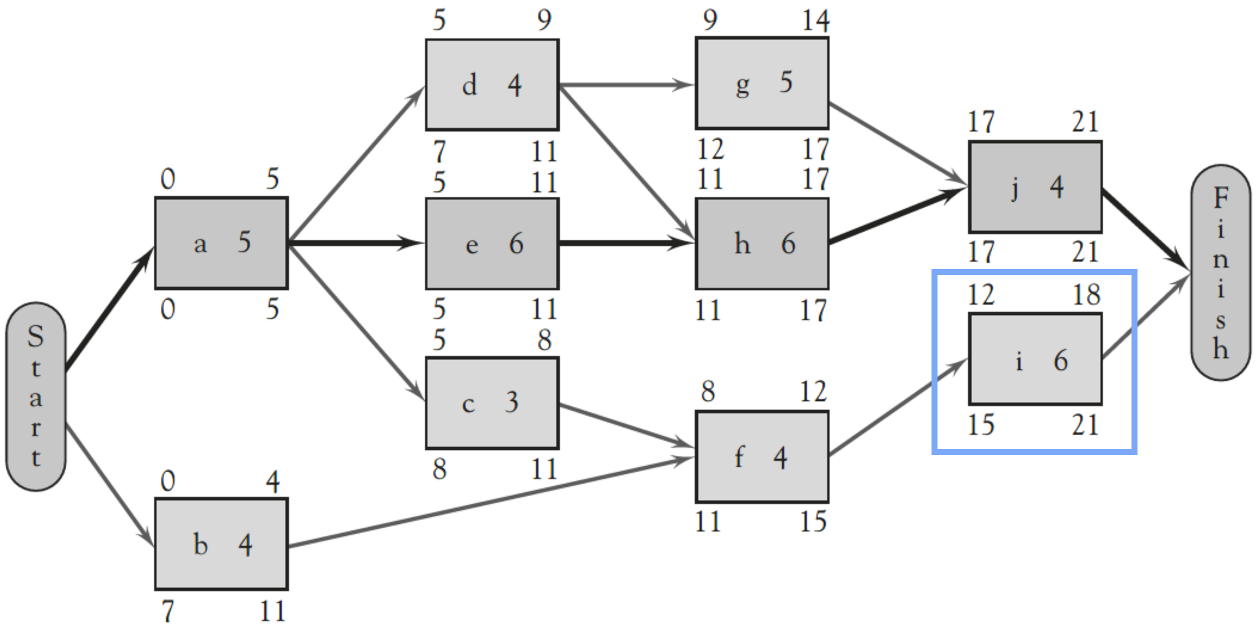
Total Float

- **Total Float (TF)** : measured by the amount of time that a schedule activity can be delayed or extended from its early start date without delaying the project finish date or violating a schedule constraint. A critical path is characterized by zero total float on the critical path
  - **Total float = LF-EF or LS-ES**
- Changes to total float indicate a threat to achieving project completion or specific milestones

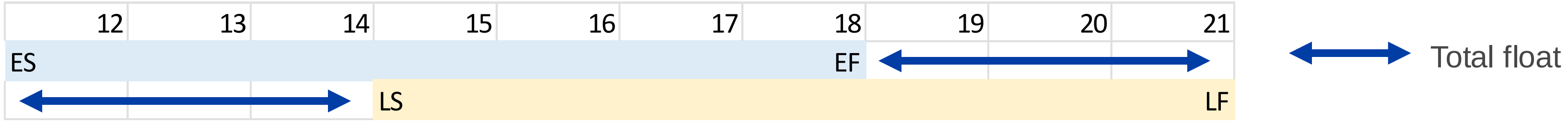




Total Float – example*



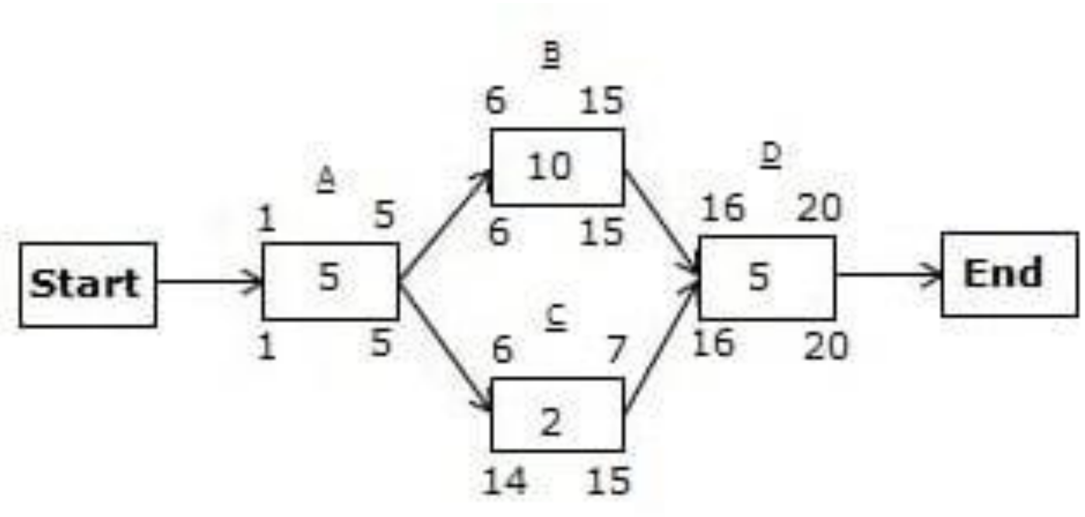
Task i:



Free float

- **Free float (FF)** : the amount of time that a schedule activity can be delayed without delaying the early start date of any successor or violating a schedule constraint
  - **Free float = ES of the earliest of its successor – EF = Min(ESsucc) - EF**
  - Free float is never a negative value
  - Indicates the amount of time a predecessor may slip before impacting its successor
  - Free float >= total float
  - When you choose to delay the start of a task, possibly for resource scheduling reasons, first consider tasks that have free float associated with them !
  - Changes to free float indicate that a lack of progress may affect immediate successors causing them to start or finish later than expected
- **Float monitoring**
  - Changes to total float indicate a threat to achieving project completion or specific milestones

Example – Free Float*

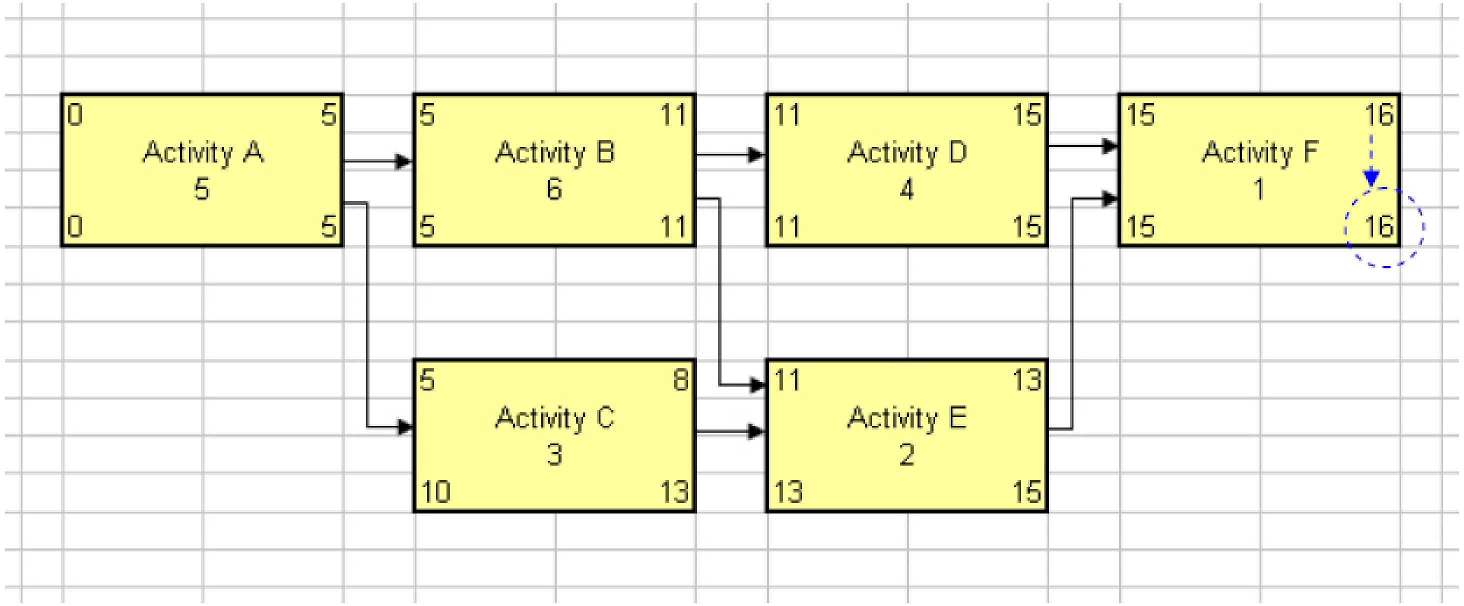


- **Calculate Free Float for each activity**

Solution

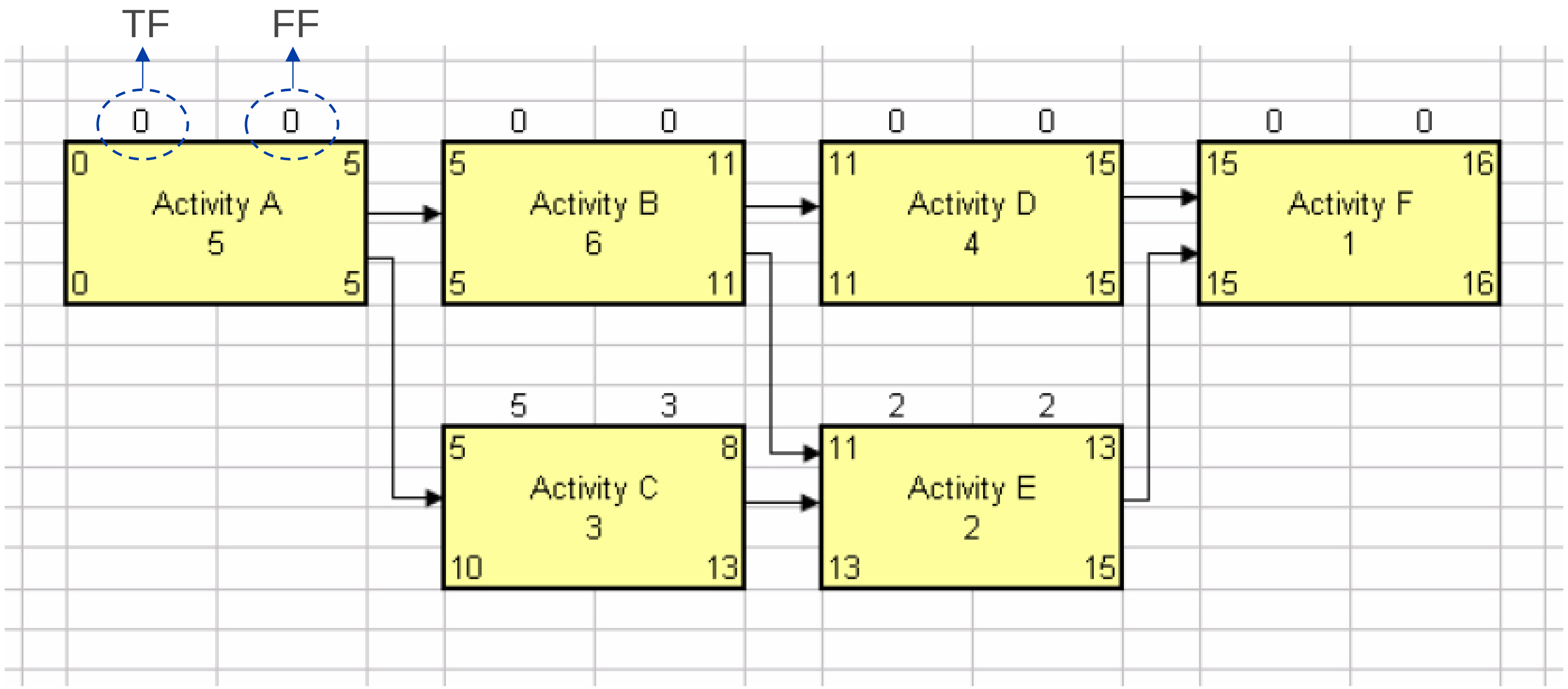
- FF(C)=9

Exercise 5*



1. Calculate TF and FF for each activity

Exercise 5 - solution



- FF(C)=11-8=3
- FF(E)=15-13=2

Project Float

- Project float: is the amount of time a Project can be delayed without delaying the externally imposed project finish date by the customer (or the project finish date previously committed to by the Project Manager)
- **Project Float = Imposed deadline – planned finish date**
- Free & Total Floats are about the time an activity can be delayed, while Project float is the amount of time a Project can be delayed.
- Project Float is usually "owned" by the PM

Float - recap

Total Float (TF)

- Amount of time that an activity can be delayed from its early start date without delaying the project finish date
- **Total float = LF-EF or LS-ES**

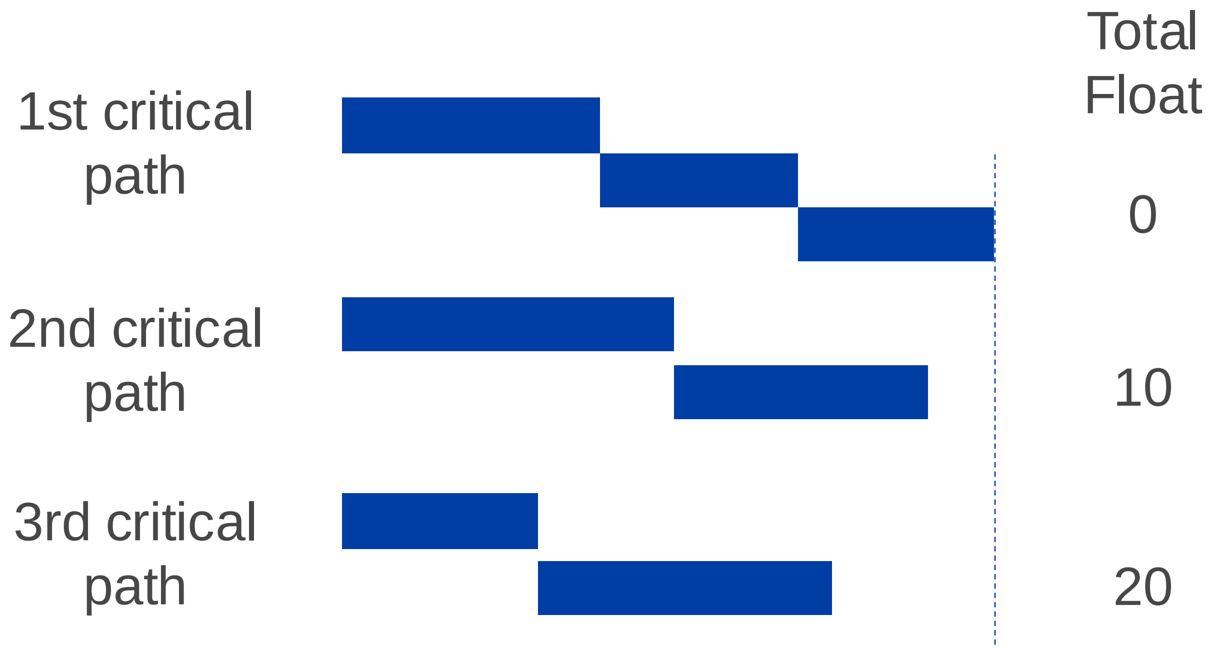
Free Float (FF)

- Amount of time that an activity can be delayed without delaying the early start date of any successor
- **Free float = Min(ESsucc) - EF**

Project Float

- Amount of time a project can be delayed without delaying the externally imposed (or internally committed) project finish date
- **Project Float = Imposed deadline – planned finish date**

Critical Path … and near critical path*



- Critical path is **dynamic**
- **Near critical path:** path close in duration to the critical path.
- The closer the near-critical and critical path are, the more risk the project has

Exercise 6

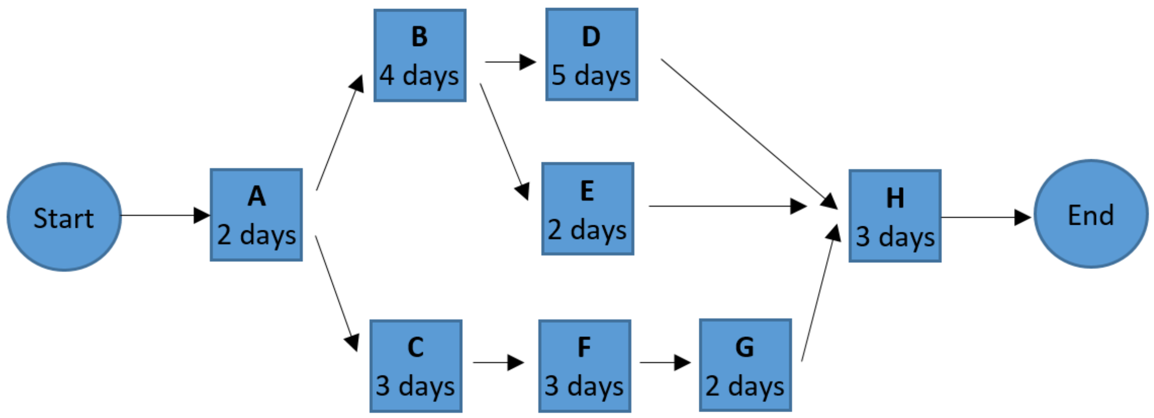
A project scheduler performs a critical path analysis on a project with a total planned duration of 1 year. He comes to the following conclusion

- “Critical path 1” has 1 month of float
- There is 1 day difference between “Critical Path 1” and “Critical path 2”

How would you proceed with the analysis ?

1. Critical path activities shouldn’t be the focus as there is 1 month of float
2. Focus on Critical Path 1
3. Focus on Critical Path 2
4. Focus on both Critical Path 1 and 2

Exercise 7*



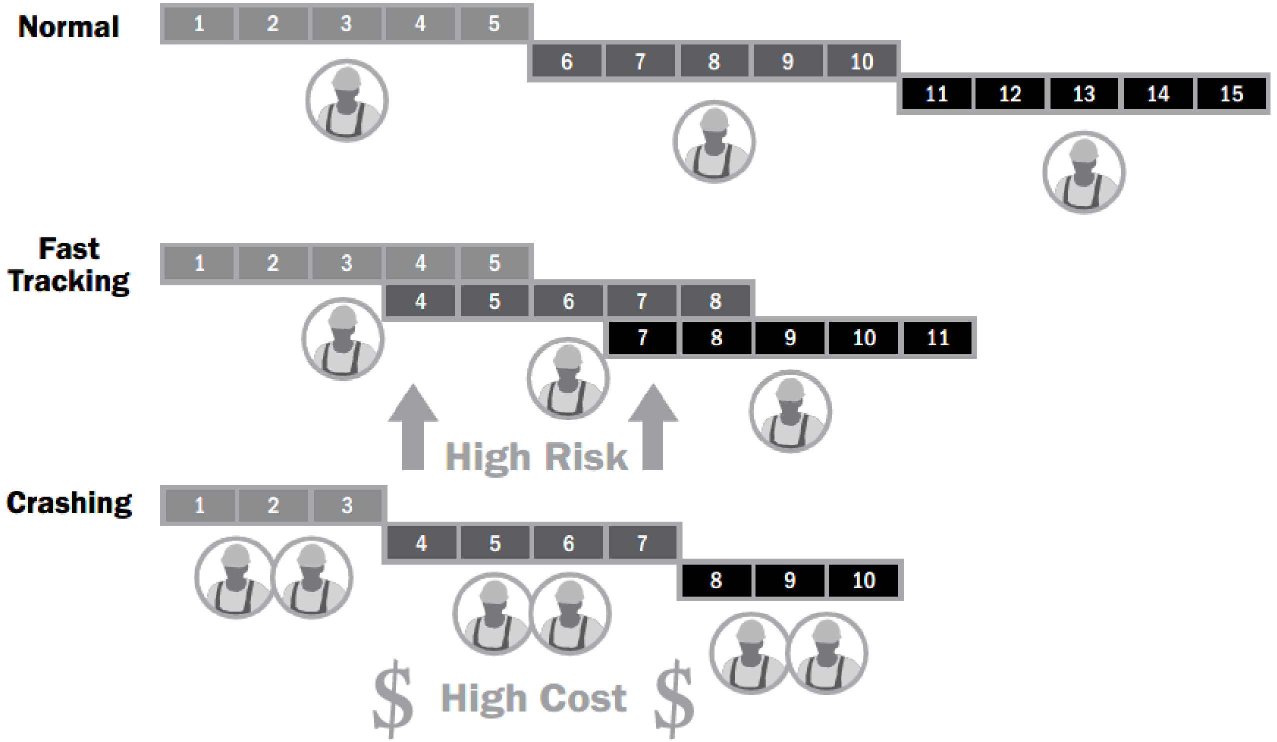
1. How many paths are possible to complete the project?
2. What is the shortest possible time to complete the project?
3. What is the longest possible to complete the project ?
4. If the customer wanted project duration is 20 days, how much is the project float?

Resource optimization

- Resource optimization = adjust the start and finish dates of activities to adjust planned resource use to be equal to or less than resource availability
- **Resource leveling**: start and finish dates are adjusted based on resource constraints with the goal of balancing the demand for resources with the available supply. Resource leveling can often cause the original critical path to change. Available float is used for leveling resources. Consequently, the critical path through the project schedule may change
- **Resource smoothing**: adjusts the activities of a schedule model such that the requirements for resources on the project do not exceed certain predefined resource limit

Schedule compression (1)

- Techniques used to shorten or accelerate the schedule duration without reducing the project scope
- **Fast tracking**: activities or phases normally done in sequence are performed in <u>parallel</u> for at least a portion of their duration
- **Crashing**: shorten the schedule duration for the least incremental cost by <u>adding resources</u>



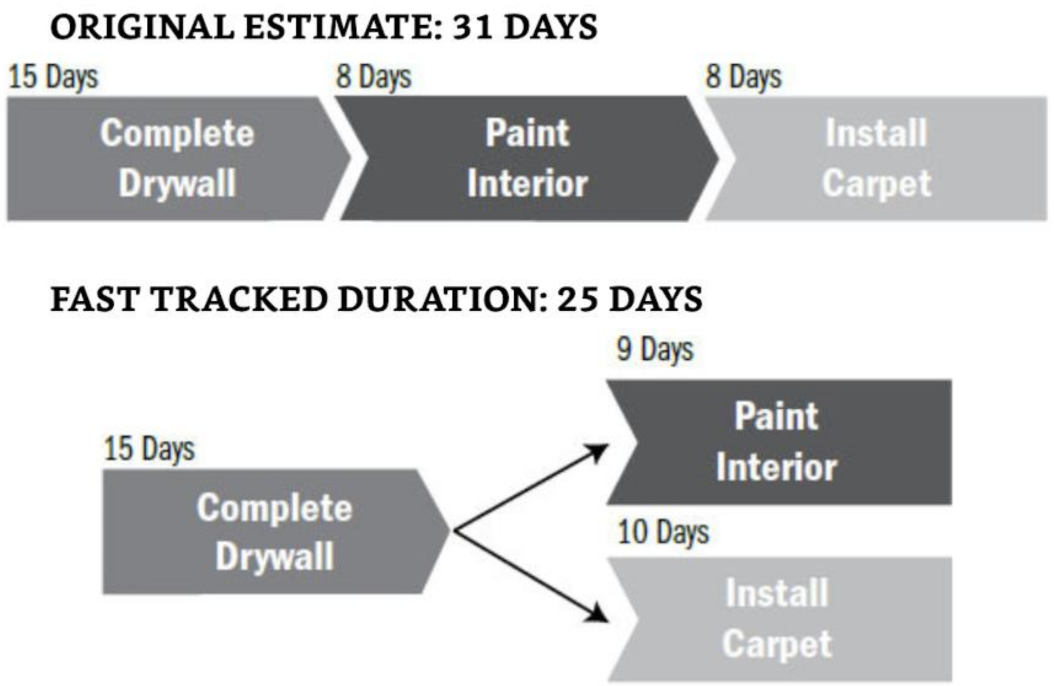
Schedule compression (2)*

ORIGINAL ESTIMATE

Activity	
200 yards of pipeline construction	
Resources	Estimated days
1	12

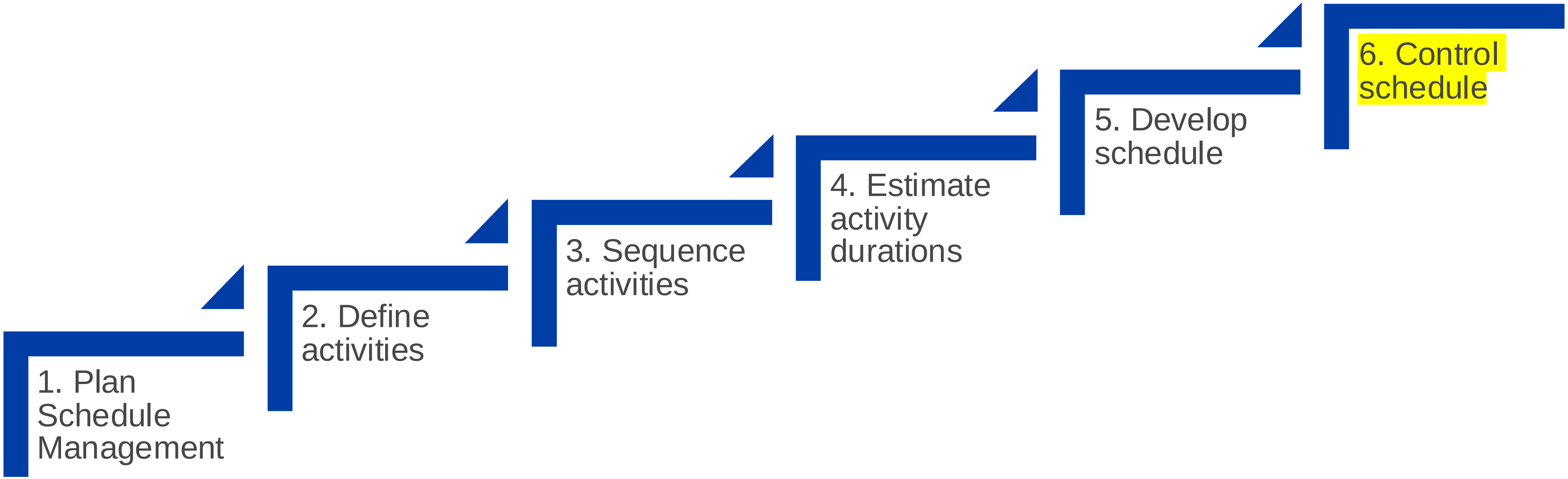
CRASHED ESTIMATE

Activity	
200 yards of pipeline construction	
Resources	Estimated days
4	4



Control Schedule

Control schedule



- **Control schedule**: process of monitoring the status of the project to update the project schedule and managing changes to the schedule baseline

Key performance indicators*

- Key performance indicators (**KPIs**): quantifiable measures to evaluate the success of a project
- **Leading indicators**
  - predict changes or trends in the project
  - can reduce performance risk by identifying potential performance variances before they cross the tolerance threshold
- **Lagging indicators**
  - measure project deliverables or events
  - reflect past performance conditions

The art of "measuring"

Why do we need to measure ?

- Where are we ?
- Data-driven decisions
- Early warnings
- Don't Let Metrics Critics Undermine Your Business (mit.edu)

However ..

- Metrics → analysis
- Relevant vs. "snazzy"
- Can you count everything ?
- Project phase

Project metrics

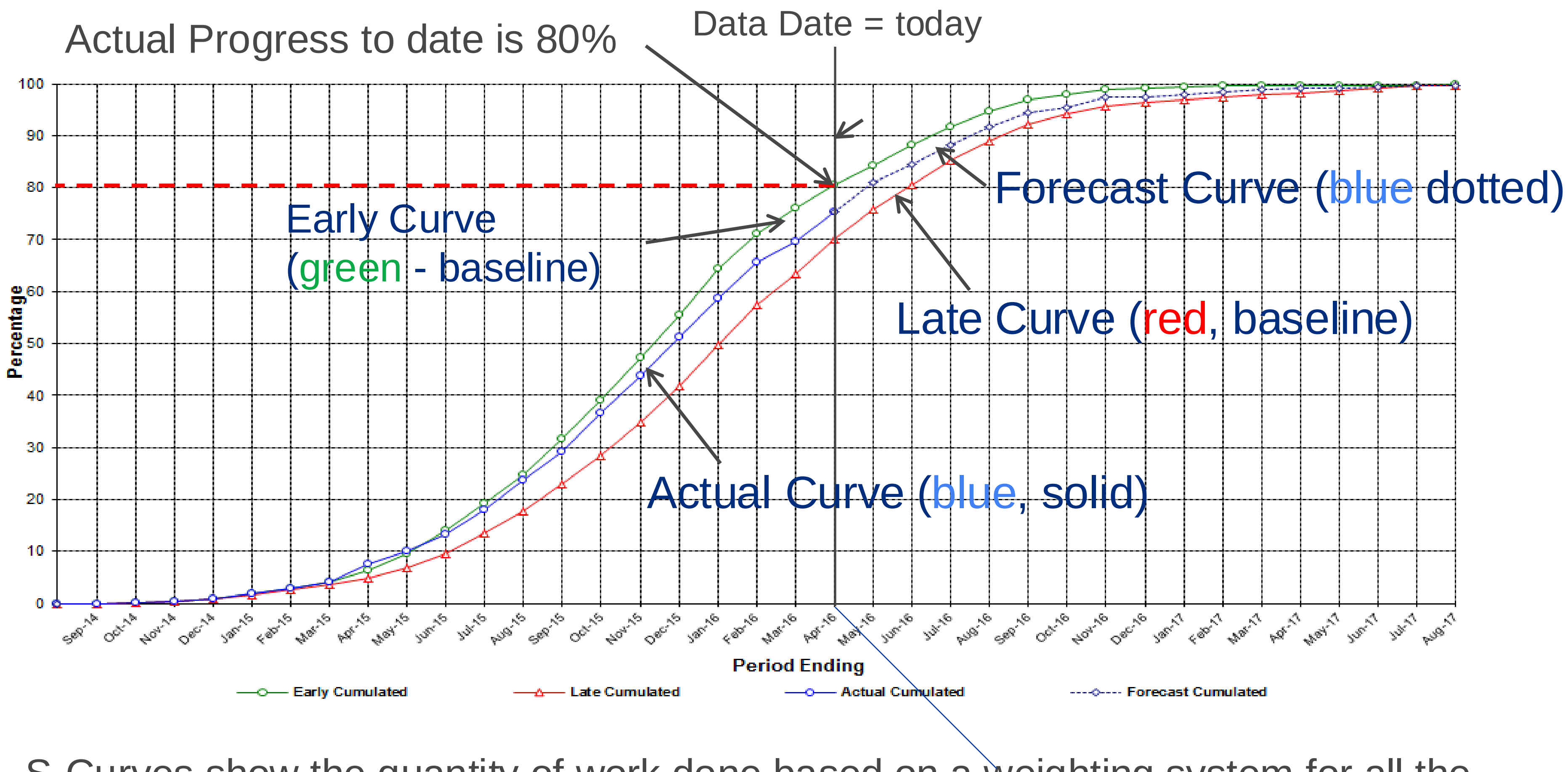
- **Baseline** schedule = version of the schedule that has been approved
- **Current** schedule = current period version of the schedule based on actual work and forecast
- **Variance** = difference between the estimated effort in the baseline and the actual effort performed by the team

Scheduling KPI’s example – start and finish dates

- Even if work is not on the critical pat, late start and finish dates indicate that the project is not performing to plan

	Baseline schedule		Current Schedule		Variances	
	Start - Planned	Finish - Planned	Start - Actual/Forecast	Finish - Actual / Forecast	Start V	Finish V
Activity A	15.01.2024	14.02.2024	15.01.2024	19.02.2024	0	5
Activity B	28.02.2024	27.06.2024	15.01.2024	15.08.2024	-44	49

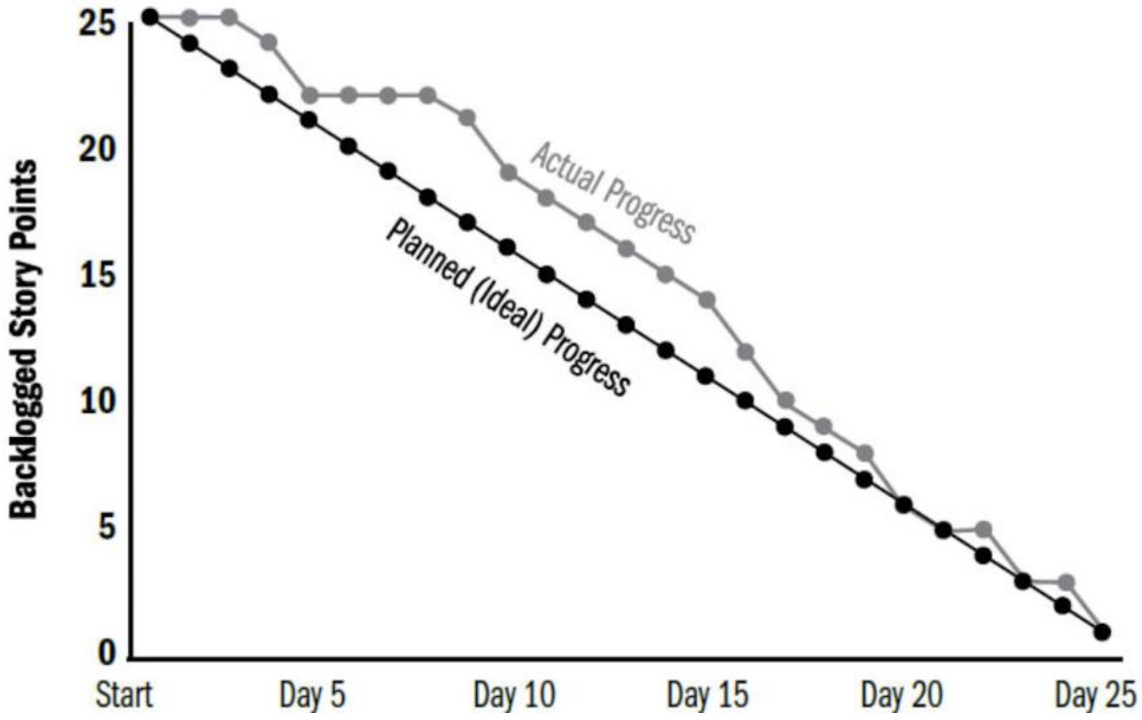
Scheduling KPI's example – S-curve



S-Curves show the quantity of work done based on a weighting system for all the project activities.

Scheduling KPI's example – Iteration Burndown Chart

- Agile tool used to display the team's progress of completing the work in the backlog.



Measurement pitfalls*

- **Hawthorne effect:** the act of measuring something influences behavior.
- **Vanity metrics:** measure that shows data but does not provide useful information for making decisions.
- **Confirmation bias**: look for and see information that supports our preexisting point of view.
- **Correlation versus causation**. confusing the correlation of two variables with the idea that one causes the other.

Agile perspective

- **Plan schedule management**: low applicability – iterations and sprints are only planned in details for the upcoming one
- **Define activities**: disaggreate to some level
- **Sequence activities**: low applicability
- **Estimate activity durations**: applicable but different approach (e.g. planning poker)
- **Develop plan**: develop release plans with planned feature to release
- **Control schedule**: done during iteration planning & retrospective

Wrap-up

Wrap-up

1. Plan schedule management	
2. Define activities	• WBS
3. Sequence Activities	• Dependencies (FS, SS, FF, SF) • Constraints (e.g. date constraints) • Leads and legs • Schedule/network health
4. Estimate Activity durations	• Techniques (analogous, parametric, bottom-up, 3-point) • 3-point estimate beta distribution • Probability of completing the project on time
5. Develop schedule	• Network types (AON, AOA) • Critical path method • Total Float, Free float, Project Float • Gantt Chart • Near critical path • Schedule compression
6. Control Schedule	• Leading and lagging indicators • Schedule Metrics • Measurement pitfalls

Exercises

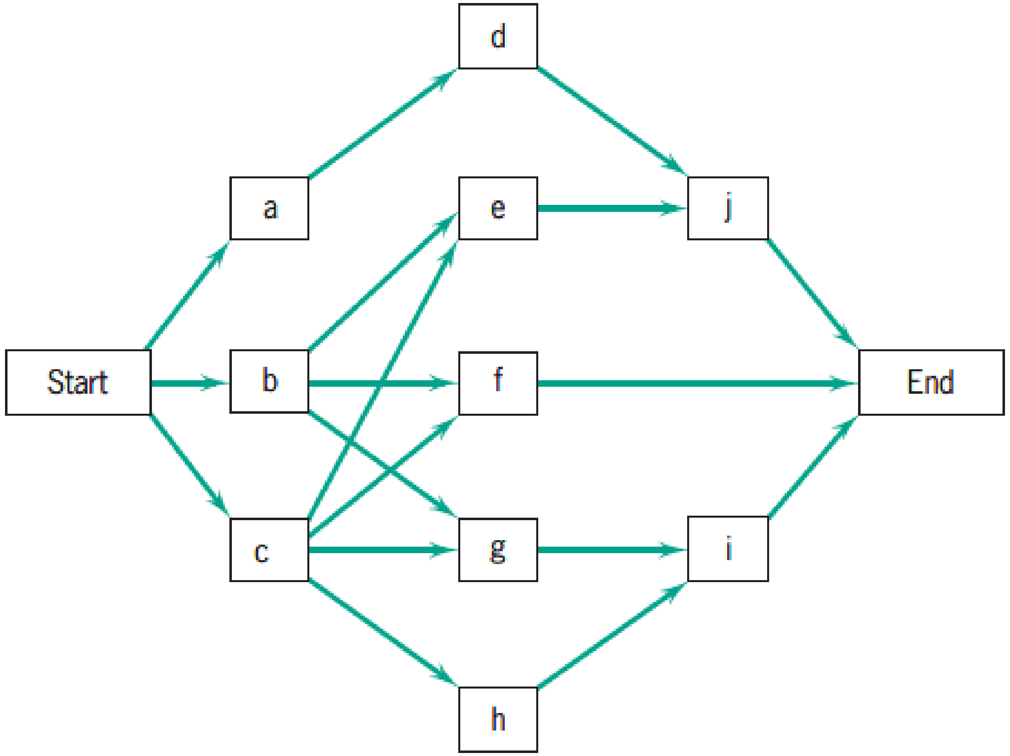
Draw network

Exercise 8 (Easy)

Activity	*Immediate Predecessor Activities*
a	—
b	—
c	—
d	a
e	b, c
f	b, c
g	b, c
h	c
i	g, h
j	d, e

- Draw the AON network

Exercise 8 - Solution

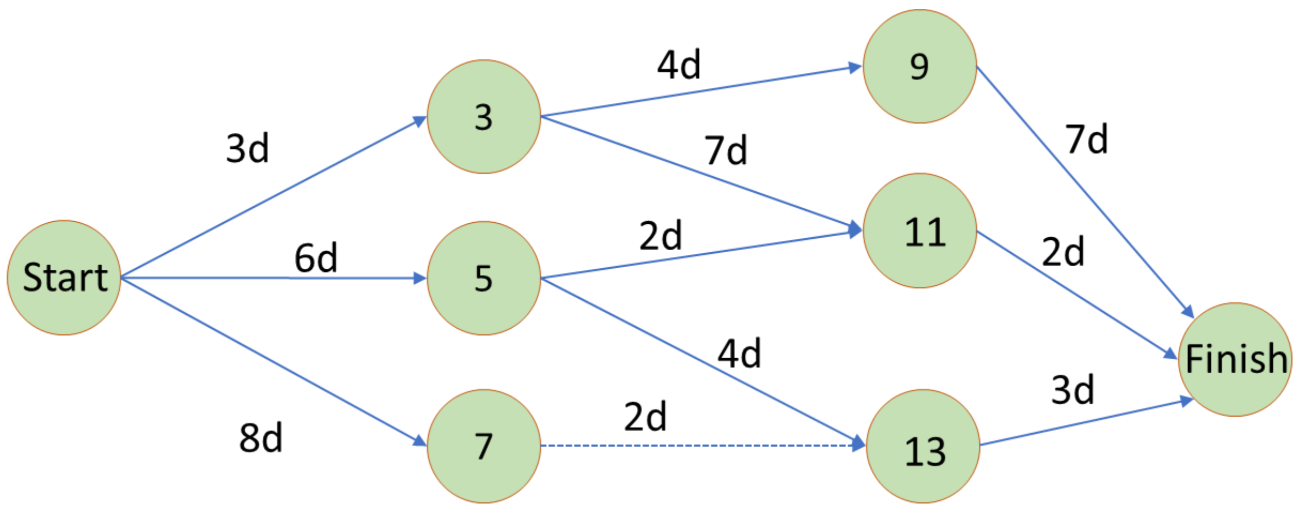


Critical path

Exercise 9 (Easy)

What is the critical path ?

A. **Start-3-9-Finish**
B. Start-3-11-Finish
C. Start-5-11-Finish
D. Start-5-13-Finish



Estimate activity durations

Exercise 10 (Easy)

Consider the following three estimates for the duration of an activity: Optimistic = 4 weeks, Most likely = 5 weeks, Pessimistic = 9 weeks

Using the beta distribution and the three-point estimating approach, the calculated Expected activity duration (tE) is:

A. 4.0 weeks

B. 4.5 weeks

C. 5.5 weeks

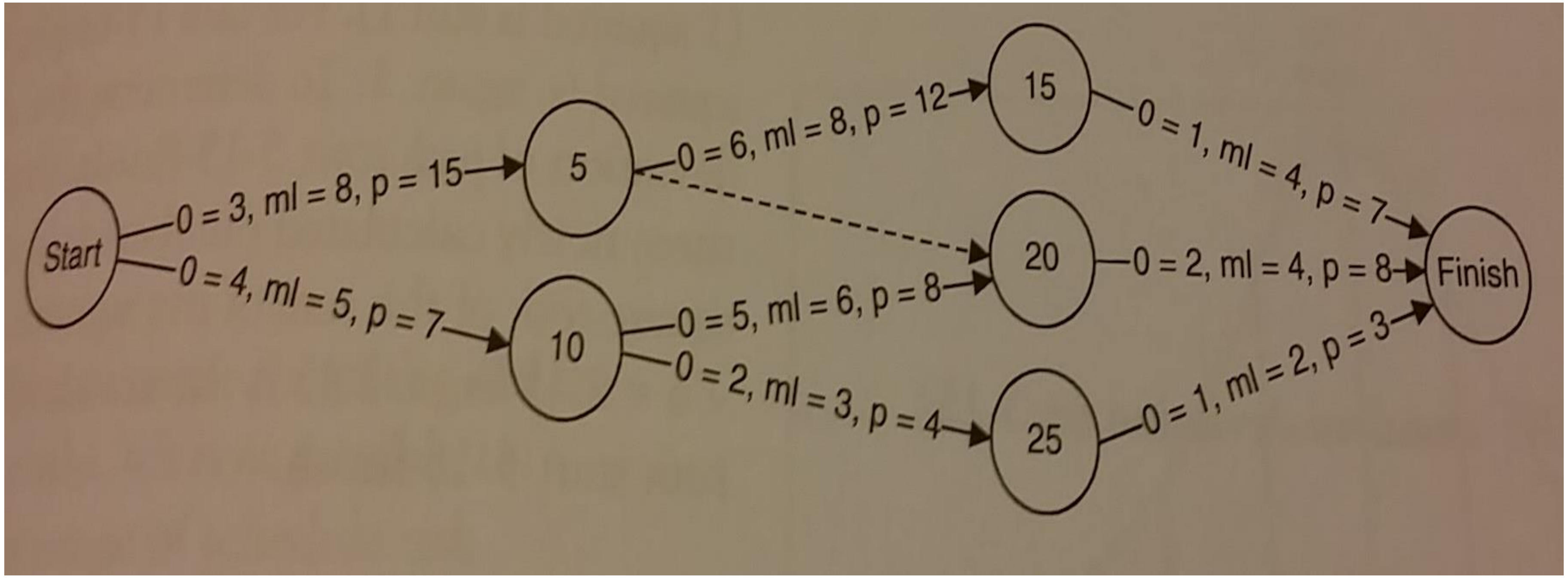
D. 6.5 weeks.

Exercise 11 (Easy)

What is the PERT duration for Start-5-15-Finish ?

O = optimistic duration, ml = most likely duration, p = pessimist duration

A. 20
B. 34
C. 20,8
D. 20,67



Exercise 12 (Easy)

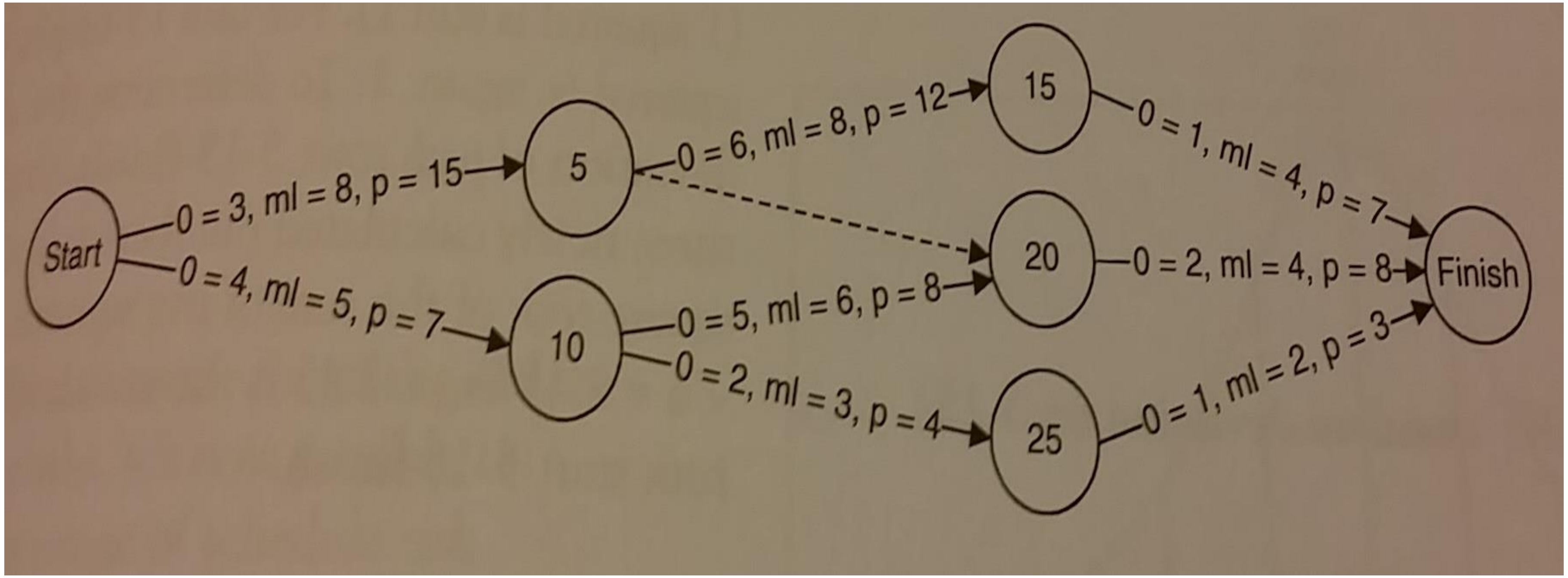
What is the PERT duration for Start-10-20-Finish ?

A. 15

B. 16.27

C. 15.67

D. 23



Exercise 13 (Easy)

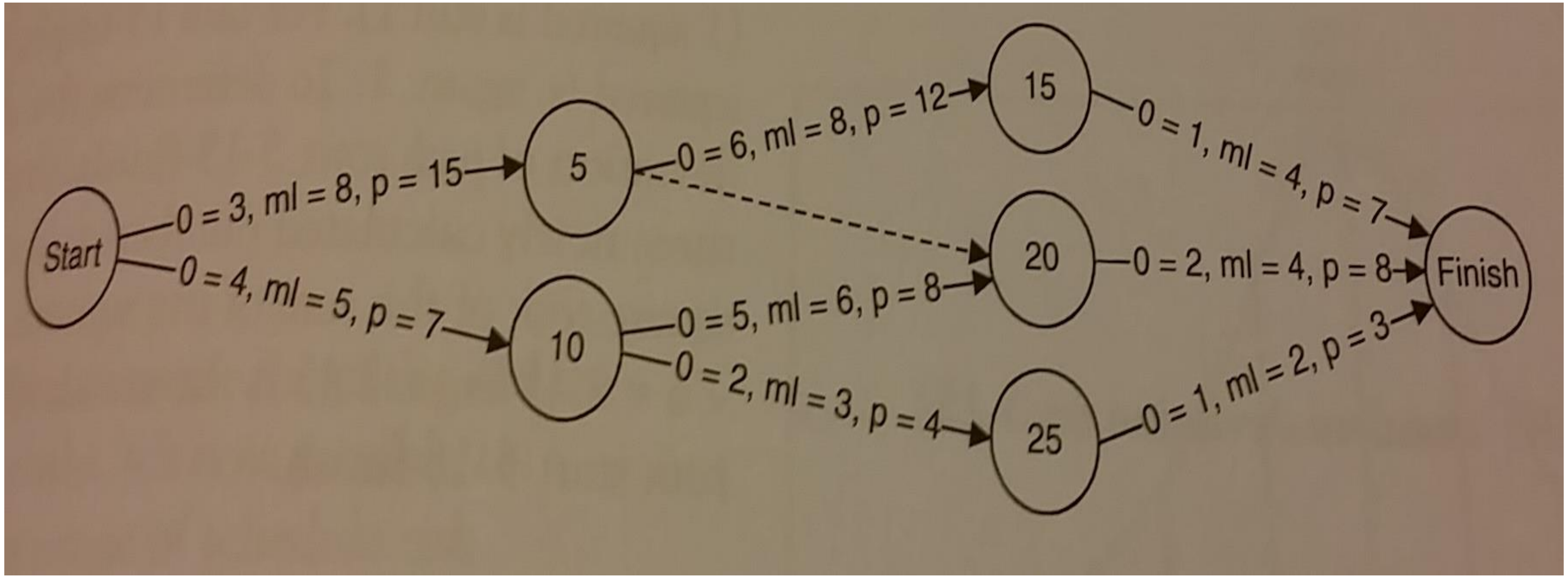
What is the PERT standard deviation for 5-15 ? What is the meaning of dotted arrow between events 5 and 20 ?

A. 0.5

B. 1

C. 2

D. 8



Exercise 14 (Easy)

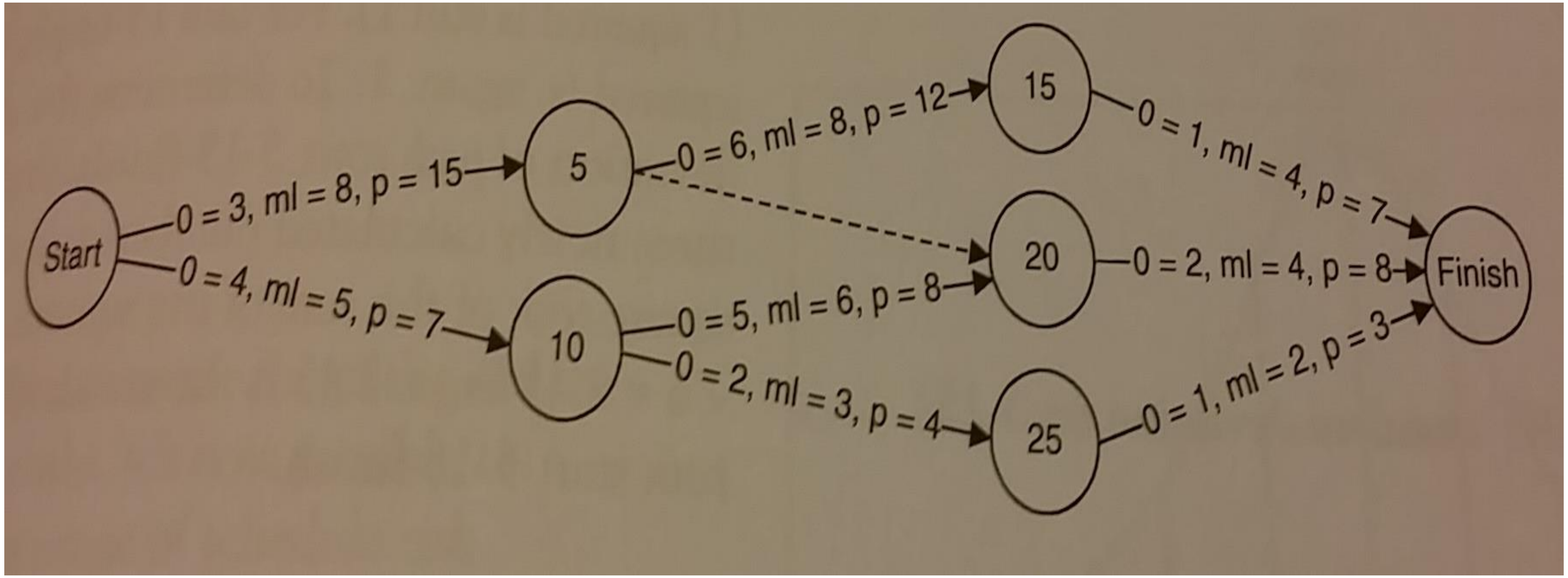
What is the PERT standard deviation for Start-5-20-Finish ?

A. **2.24**

B. 1.73

C. 3

D. 5



Exercise 15 (Medium)

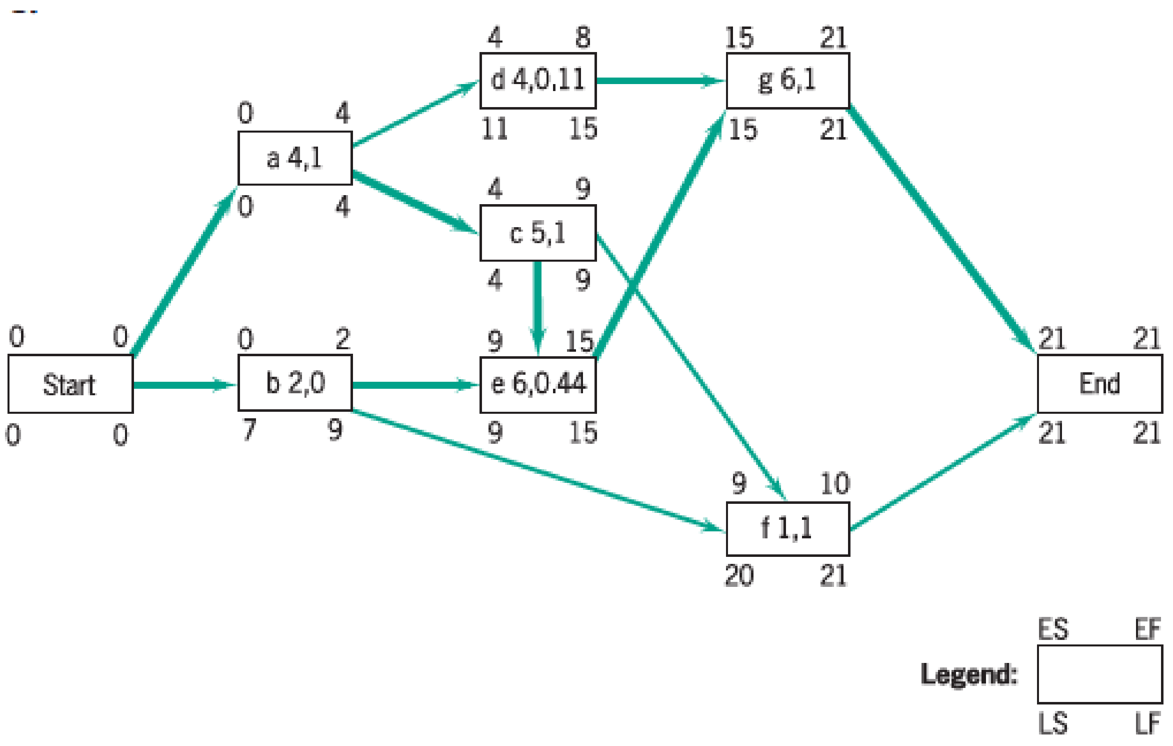
Consider the following project (times given in days).

Activity	*a*	*m*	*b*	*Predecessors*
a	1	4	7	—
b	2	2	2	—
c	2	5	8	a
d	3	4	5	a
e	4	6	8	c,b
f	0	0	6	c,b
g	3	6	9	d,e

Find:

1. The network.
2. All expected activity times, variances, and slacks.
3. The critical path and expected completion time.
4. The probability the project will be done in 23 days.
5. The completion time corresponding to 95% probability.

Exercise 15 - solution



Activity	*TE*	σ^2	*Slack*
a	4	1.00	0
b	2	0	7
c	5	1.00	0
d	4	0.11	7
e	6	0.44	0
f	1	1	11
g	6	1	0

3. Critical path is a-c-e-g for a time of 21 days.

4. $Z = (23 - 21)/\sqrt{3.44} = 1.078$ for a probability of 85.9%.

5. $P = 0.95$ corresponds to $Z = 1.65 = (T - 21)/1.855$, or $T = 24.06$ days.

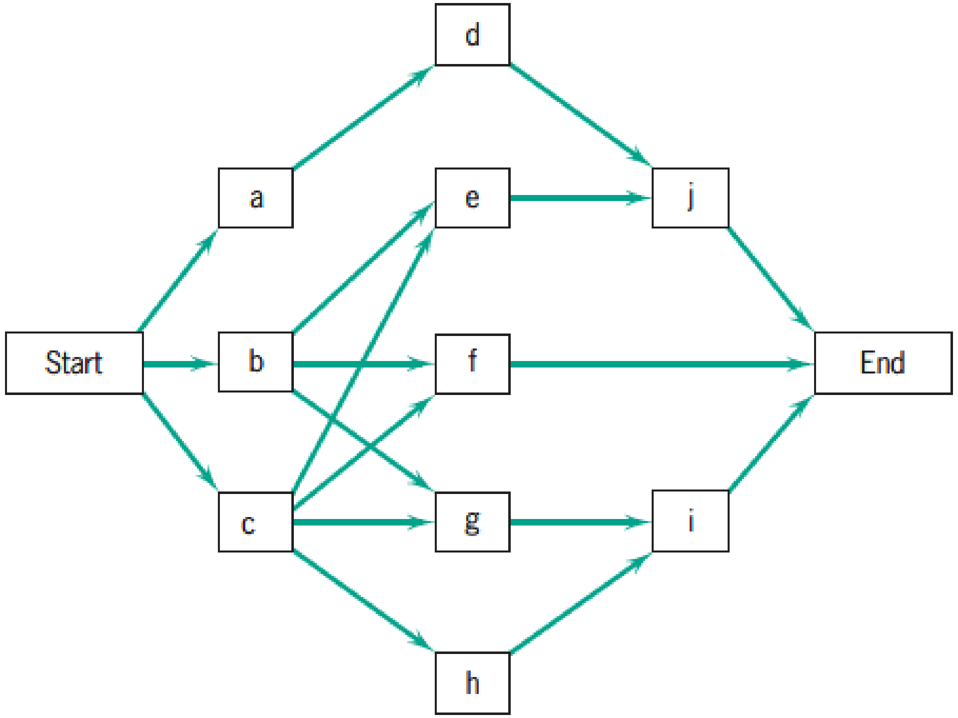
Activity durations and critical path

Exercise 16 (Medium)

Activity	*Optimistic Time*	*Most Likely Time*	*Pessimistic Time*	*Immediate Predecessor Activities*
a	10	22	22	—
b	20	20	20	—
c	4	10	16	—
d	2	14	32	a
e	8	8	20	b, c
f	8	14	20	b, c
g	4	4	4	b, c
h	2	12	16	c
i	6	16	38	g, h
j	2	8	14	d, e

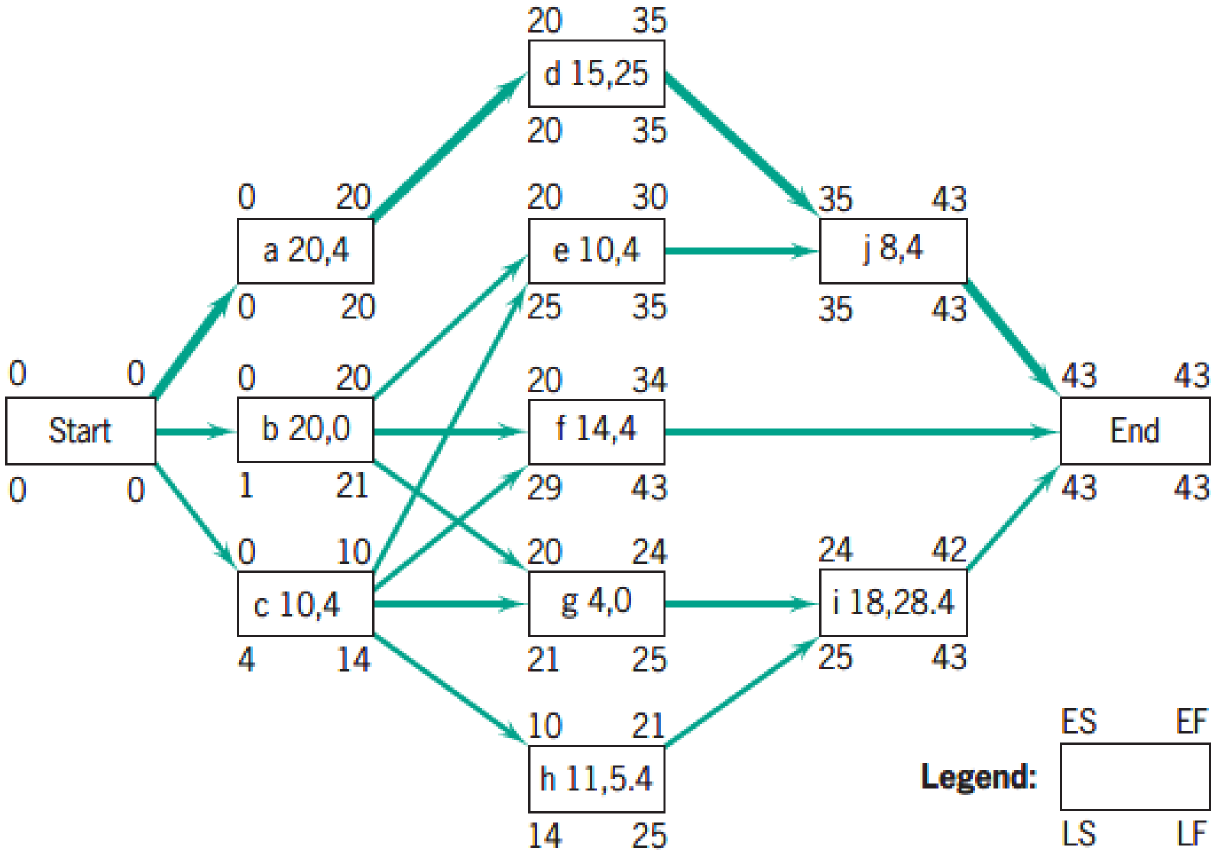
1. Draw the AON network
2. Calculate
   - Expected activity times (Te)
   - Variances
   - Standard Deviations
3. Calculate
   - ES, EF, LS, LF
4. Calculate the total float for each activity

Exercise 16 – solution (1)



Activity	Expected Time, TE	Variance, σ^2	Standard Deviation, σ
a	20	4	2
b	20	0	0
c	10	4	2
d	15	25	5
e	10	4	2
f	14	4	2
g	4	0	0
h	11	5.4	2.32
i	18	28.4	5.33
j	8	4	2

Exercise 16 – solution (2)



Activity	LS	ES	Slack
a	0	0	0
b	1	0	1
c	4	0	4
d	20	20	0
e	25	20	5
f	29	20	9
g	21	20	1
h	14	10	4
i	25	24	1
j	35	35	0

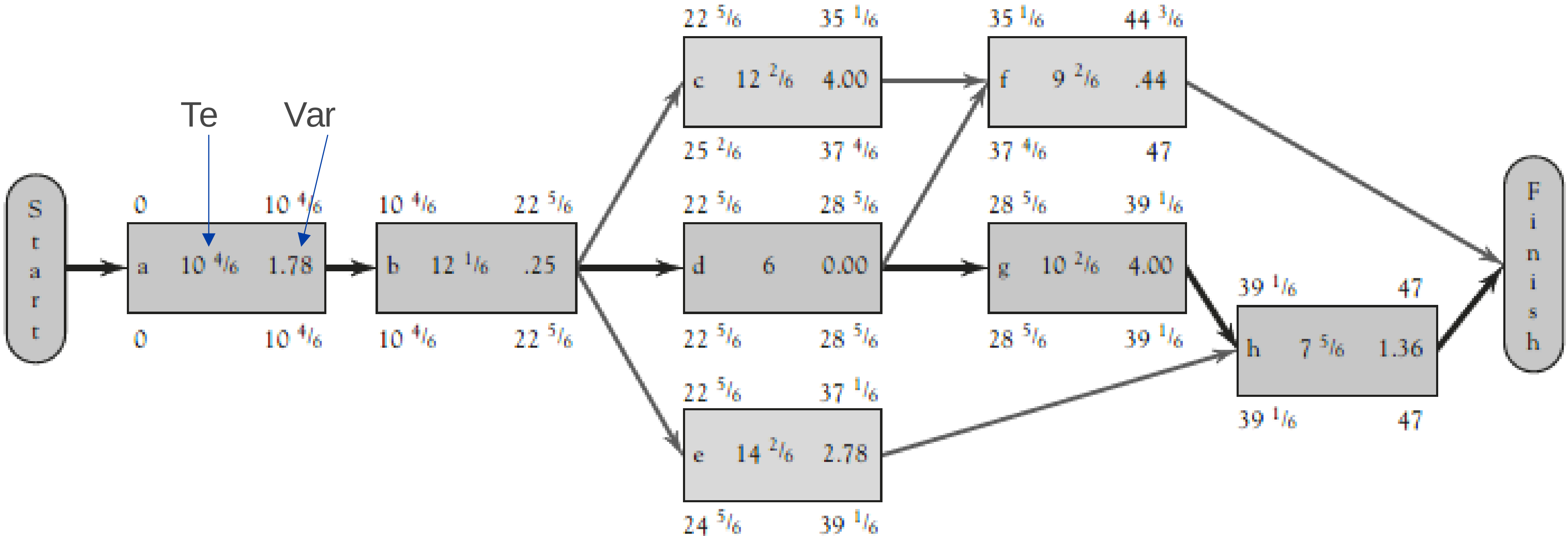
Exercise 17 (Difficult)

Activity	Pred	Opt. a	M. Likely m	Pess. b
a	—	8	10	16
b	a	11	12	14
c	b	7	12	19
d	b	6	6	6
e	b	10	14	20
f	c, d	6	10	10
g	d	5	10	17
h	e, g	4	8	11

Calculate

1. Critical path
2. Te and Variance for each activity
3. Project Expected critical time
4. Variance of the project
5. Probability that the critical path will be completed on or before Day 50
6. Probability that the project will be completed on or before Day 50
7. What would be the promised completion date with 95% probability ?
8. What is the probability of delivering the project in 45 days ?

Exercise 17 - Solution (1)



1) Critical path = a-b-d-g-h
3) Expected critical time = 47 days
4) Variance = 7.39 days
5) Probability = 86%
6) Probability = 83%
7) Probability = 51.5 days
8) Probability = 23%

Exercise 18 (Medium)

Activity	Optimistic duration	Most likely duration	Pessimistic duration
A	12	27	47
B	45	60	92
C	39	44	48
D	29	37	42

Using PERT 3-point estimating, calculate

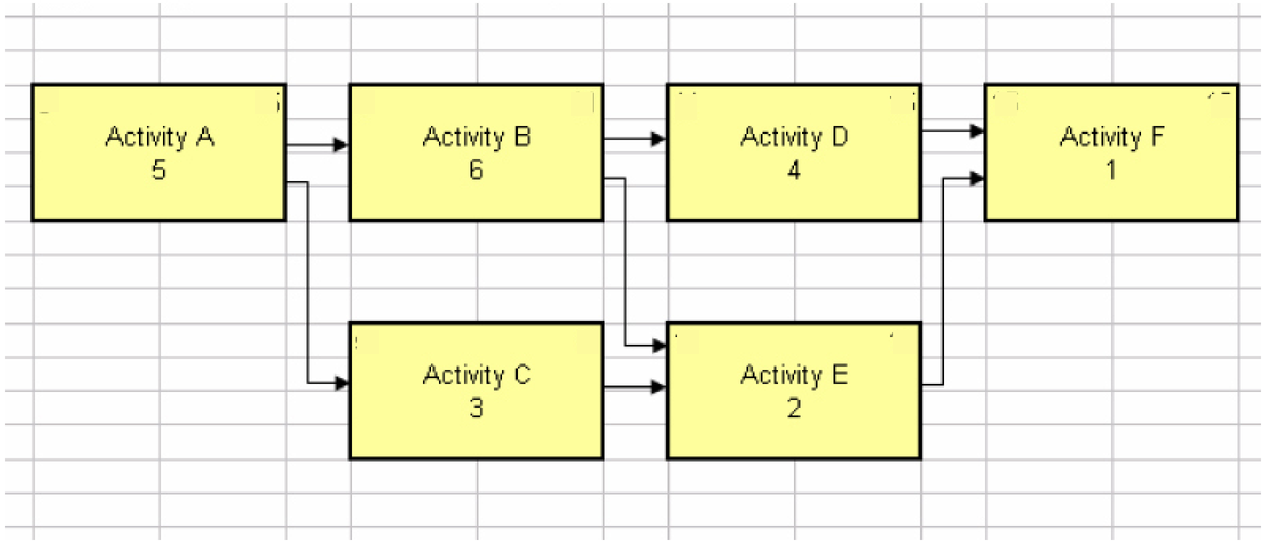
1. PERT duration of each activity
2. PERT standard deviation of each activity
3. What is the meaning of the standard deviation
4. If all the above activities are on the critical path, what is the project's mean duration and standard deviation?

1) PERT dur (A)=27.8, PERT dur (B)=62.8, PERT dur (C)=43.8, PERT dur (D)=36.5
2) PERT std dev(A)=5.8, PERT std dev(B)=7.8, PERT std dev(C)=1.5, PERT std dev(D)=2.2
3) measure of "how spread out" a distribution is from the mean
4) Project mean = 171, Std Dev = 10.1

Project Libre

Exercise 19 (Medium)

Exercise with Project Libre https://www.projectlibre.com/



Given the network on the left-hand side, use Project Libre to analyze and display the following parameters

- Critical path
- Project duration

For each activity

- Total Float
- Free Float
- ES, EF, LS, LF

Assume that the project start date is 1-Jan-23 and use a 24h calendar

Exercise 19 - Solution

	Name	Duration	Free Slack	Total Slack	Early Start	Early Finish	Late Start	Late Finish	Predecessors
1	A	5 days	0 days	0 days	1/2/23 8:00 AM	1/4/23 12:00 AM	1/2/23 8:00 AM	1/4/23 12:00 AM	
2	B	6 days	0 days	0 days	1/4/23 12:00 AM	1/6/23 12:00 AM	1/4/23 12:00 AM	1/6/23 12:00 AM	1
3	C	3 days	3 days	5 days	1/4/23 12:00 AM	1/5/23 12:00 AM	1/5/23 4:00 PM	1/6/23 4:00 PM	1
4	D	4 days	0 days	0 days	1/6/23 12:00 AM	1/7/23 8:00 AM	1/6/23 12:00 AM	1/7/23 8:00 AM	2
5	E	2 days	2 days	2 days	1/6/23 12:00 AM	1/6/23 4:00 PM	1/6/23 4:00 PM	1/7/23 8:00 AM	2;3
6	F	1 day	0 days	0 days	1/7/23 8:00 AM	1/7/23 4:00 PM	1/7/23 8:00 AM	1/7/23 4:00 PM	4;5