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Chapter 3:
PROJECT MANAGEMENT

Learning Objectives

1. Use a Gantt chart for scheduling
2. Draw AON networks
3. Complete forward and backward passes for a project
4. Determine a critical path
5. Calculate the variance of activity times
6. Crash a project

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Project Management

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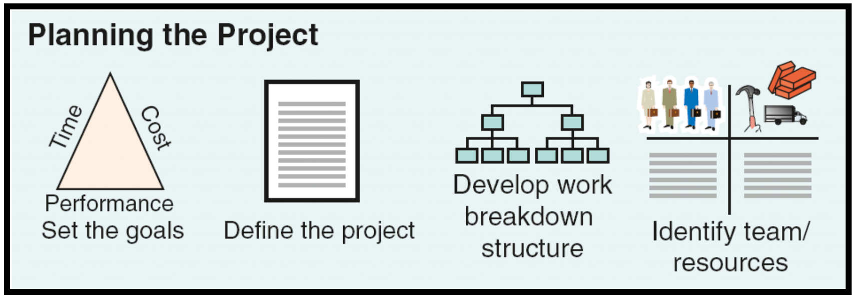
- A project is a temporary and often customized initiative that consists of many smaller tasks and activities that must be coordinated and completed to finish the entire initiative on time and within budget

- Project management involves all activities associated with planning, scheduling, and controlling projects
  - Planning: goal setting, defining the project, team organization
  - Scheduling: relates people, money, and supplies to specific activities
  - Controlling: monitors resources, costs, quality, and budgets; revises plans and shifts resources to meet time and cost demands

Phase 1: Project Planning

- Project Planning
  - Establishing objectives
  - Defining project
  - Creating Work Breakdown Structure (WBS)
  - Determining resources
  - Forming organization



- Project Organization
  - Often temporary structure
  - Uses specialists from entire company
  - Headed by project manager
    - Coordinates activities
    - Monitors schedule and costs
  - Permanent structure called ‘matrix organization’

Work Breakdown Structure

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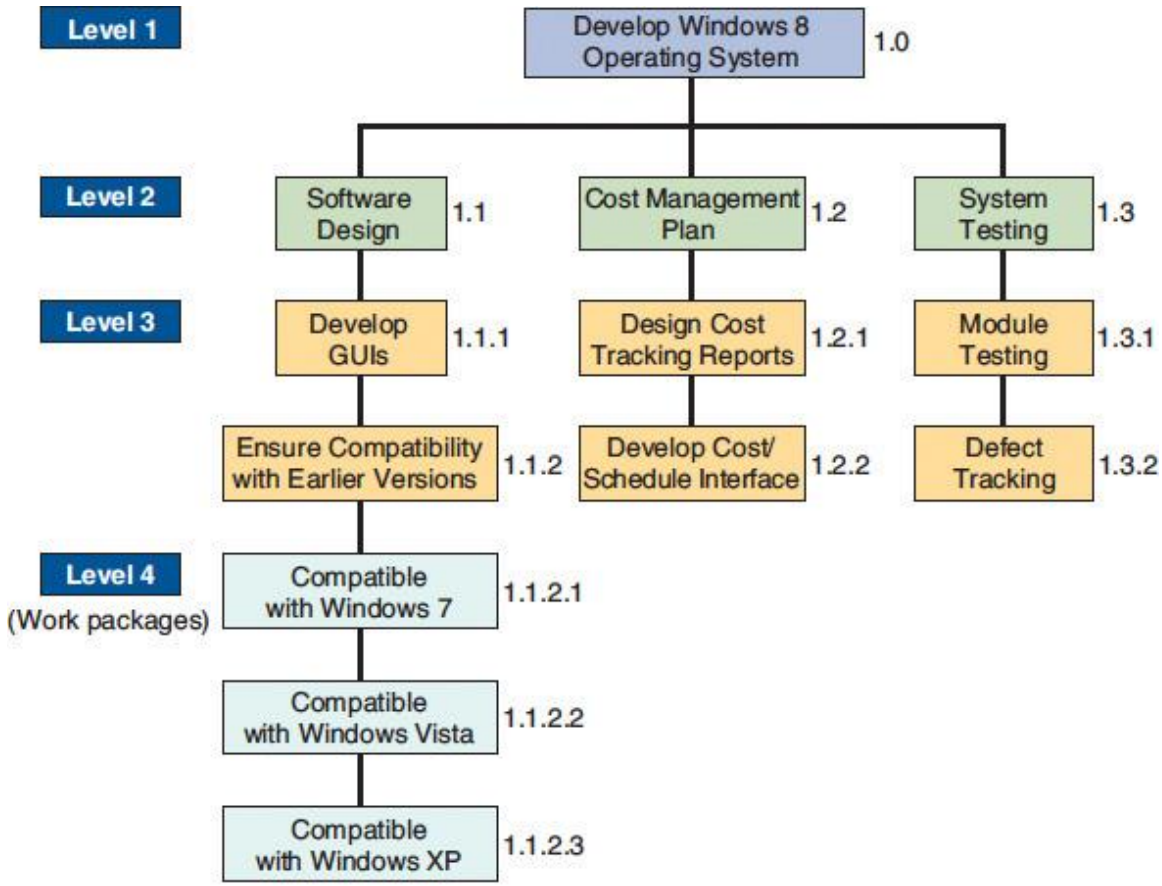
- Work Breakdown Structure (WBS): a hierarchical description of a project into more and more detailed components



Phase 2: Project Scheduling

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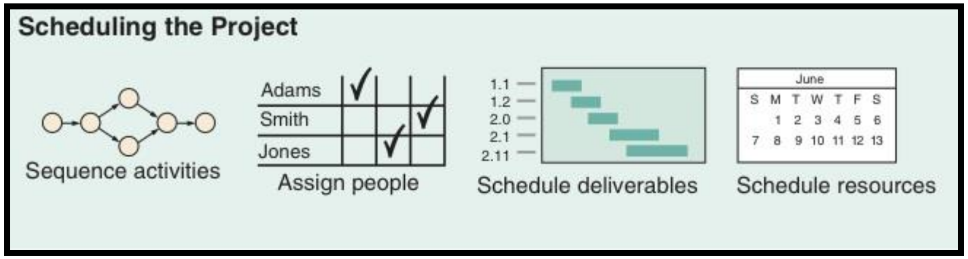
- Project scheduling
  - Identifying precedence relationships
  - Sequencing activities
  - Determining activity times & costs
  - Estimating material & worker requirements
  - Determining critical activities



- Scheduling techniques
  - Ensure that all activities are planned for
  - Their order of performance is accounted for
  - The activity time estimates are recorded
  - The overall project time is developed

Project Scheduling Charts

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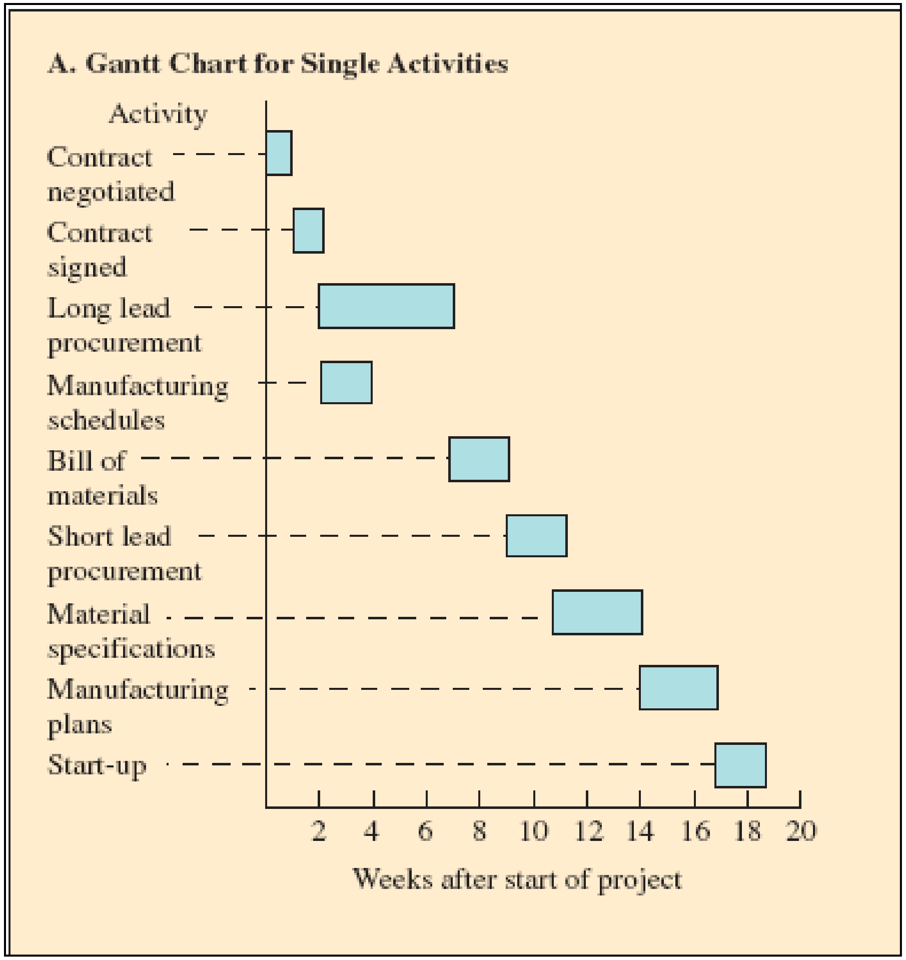
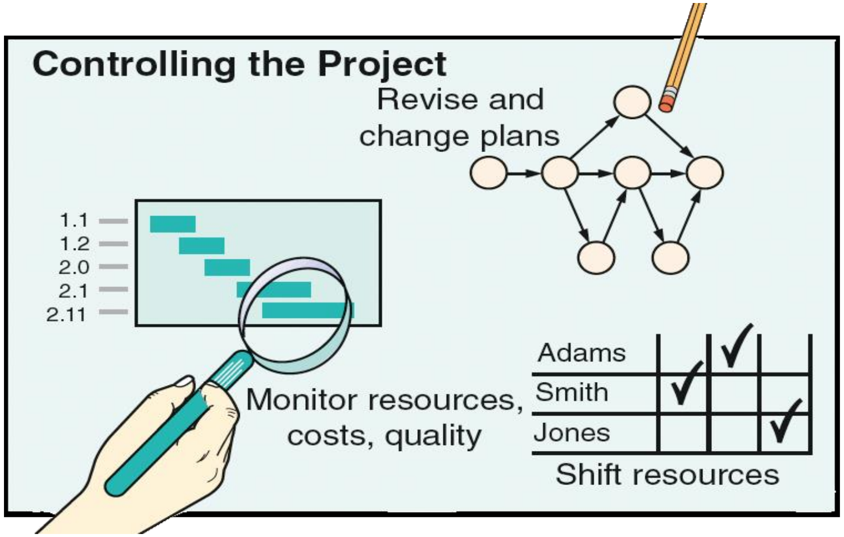
- Charts are useful because their visual presentation is easily understood
- Software is available to create the charts
- Gantt chart: a bar chart showing both the amount of time involved and the sequence in which activities can be performed

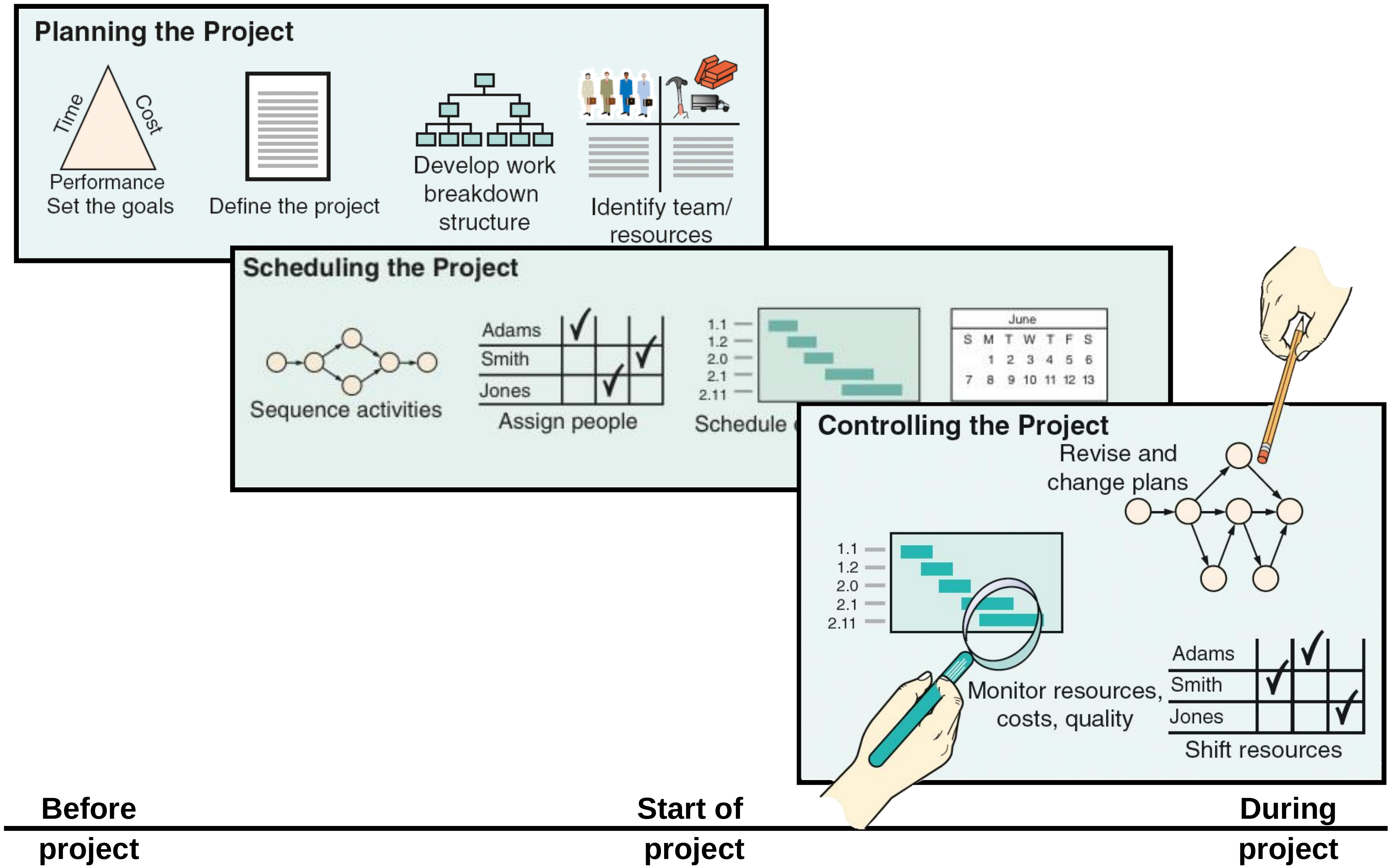


Phase 3: Project Controlling

- Detailed cost breakdowns for each task
- Total program labor curves
- Cost distribution tables
- Functional cost and hour summaries
- Raw materials and expenditure forecasts
- Variance reports
- Time analysis reports
- Work status reports



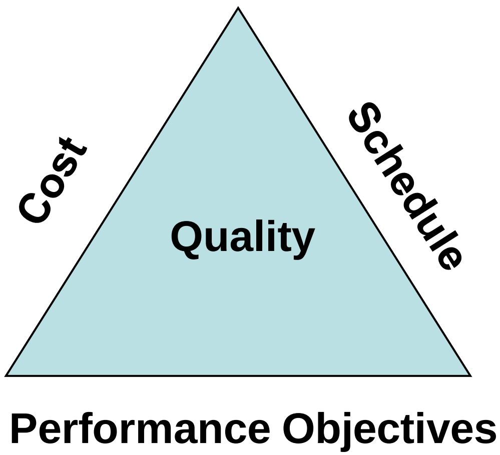
Project Planning, Scheduling, and Controlling Timeline



Several Principles for Project Managers

- Manage people individually and as a project team
- Reinforce the commitment and excitement of the project team
- Keep everyone informed
- Build agreements and consensus among the team
- Empower the project team

The "Project Management Triangle"



Contributors/Impediments to Project Success

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Contributors to Project Success:

- Well-defined and agreed-upon objectives
- Top-management support
- Strong project manager leadership
- Well-defined project definition
- Accurate time and cost estimates
- Teamwork and cooperation
- Effective use of project management tools
- Clear channels of communication
- Adequate resources and reasonable deadlines
- Constructive response to conflict

Impediments to Project Success:

- Ill-defined project objectives (scope creep)
- Lack of executive champion
- Inability to develop and motivate people
- Poorly defined project definition
- Lack of data accuracy and integrity
- Poor interpersonal relations and teamwork
- Ineffective use of project management tools
- Poor communication
- Unreasonable time pressures and lack of resources
- Inability to resolve conflict

Ethical Issues

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- Project managers face many ethical decisions on a daily basis.
- The Project Management Institute (www.pmi.org) has established an ethical code to deal with problems such as:
  - Offers of gifts from contractors
  - Pressure to alter status reports to mask delays
  - False reports for charges of time and expenses
  - Pressure to compromise quality to meet schedules
  - Project Management Professional (PMP) is a professional certification offered by the PMI

PMI®
Project Management Institute

Network Planning Techniques: CPM & PERT

- Developed in 1950's
  - Critical Path Method (CPM) by DuPont for chemical plants (1957)
  - Project Evaluation and Review Technique (PERT) by Booz, Allen & Hamilton with the U.S. Navy, for Polaris missile (1958)
- Both consider precedence relationships and interdependencies
- Each uses a different estimate of activity times
  - CPM assumes we know a *fixed time* estimate for each activity and there is no variability in activity times
  - PERT uses a probability distribution for activity times to allow for *variability*

Advantages of CPM/PERT

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- Especially useful when scheduling and controlling large projects
- Straightforward concept and not mathematically complex
- Graphical networks help highlight relationships among project activities
- Critical path and slack time analyses help pinpoint activities that need to be closely watched
- Project documentation and graphics point out who is responsible for various activities
- Applicable to a wide variety of projects
- Useful in monitoring not only schedules but costs as well

Limitations of CPM/PERT

- Project activities must be clearly defined, independent, and stable in their relationships
- Precedence relationships must be specified and networked together
- Time estimates tend to be subjective and are subject to fudging by managers
- There is an inherent danger of too much emphasis being placed on the longest, or critical, path

CPM and PERT Steps

- General Steps

1. Define the project and prepare the work breakdown structure
2. Develop relationships among the activities - decide which activities must precede and which must follow others
3. Draw the network connecting all of the activities
4. Assign time and/or cost estimates to each activity
5. Compute the longest time path through the network – this is called the critical path
6. Use the network to help plan, schedule, monitor, and control the project

Activity on Node (AON) Network Conventions

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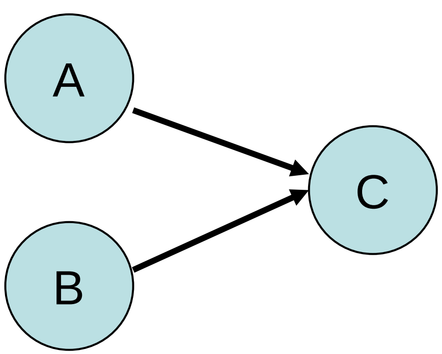
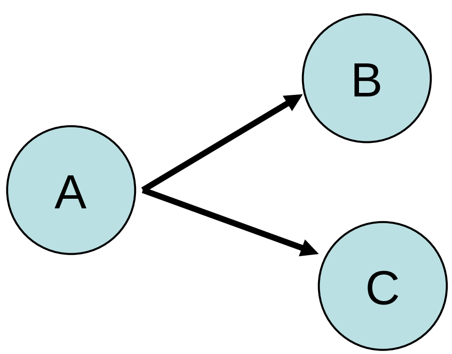
- Under AON method, nodes (circles) represent activities and arcs (arrows) define the precedence relationships between activities
  - <u>Immediate predecessor</u>: activity that needs to be completed immediately *before* another activity
  - Many project management software packages use AON networks - we will focus on this method. Conventions:



Both **A** and **B** must be complete before **C** can start



A must be complete before **B** or **C** can start

Critical Path Method Definitions

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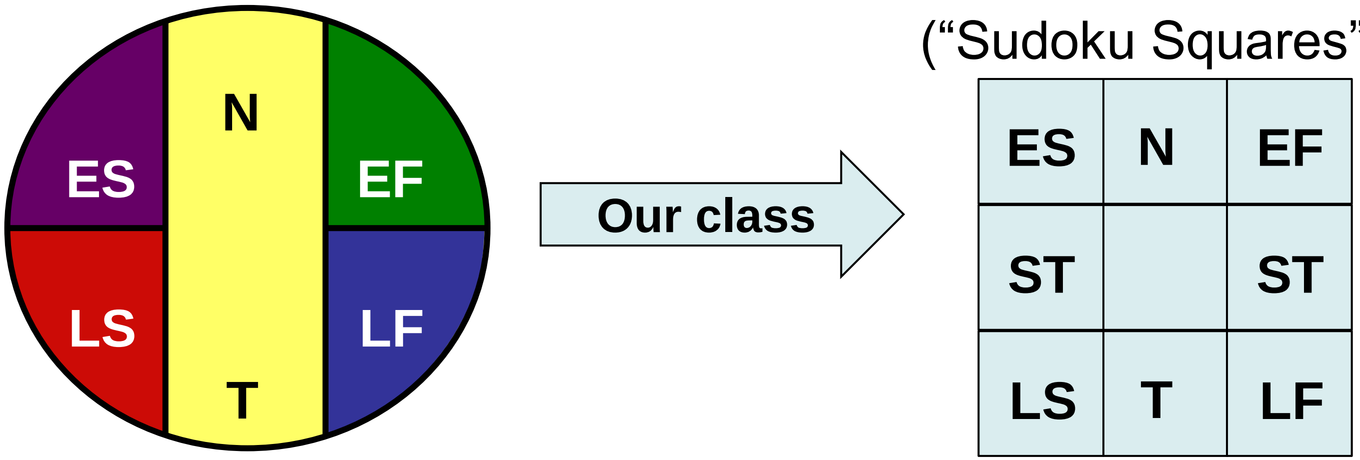
- Critical Path Method (CPM): an approach to scheduling and controlling project activities
- Critical path: the sequence of activities that takes the longest time and defines the total project completion time
- Critical activities: Activities on the critical path
- Slack: Allowable slippage for path; the difference in the length of path and the length of critical path
- Nodes in the project network are replaced with boxes ("Sudoku Squares") that provide information to determine the duration of each path

CPM Analysis

Text Method:

Alternate Method (“Sudoku Squares”):



N: Identification **N**umber or symbol for the activity

T: Activity duration, normal **T**ime to complete the activity

ES: **E**arliest **S**tart**,** earliest time at which an activity can start, assuming all predecessors have been completed

EF: **E**arliest **F**inish**,** earliest time at which an activity can be finished

LS: **L**atest **S**tart**,** latest time at which an activity can start so as to not delay the completion time of the entire project

LF: **L**atest **F**inish**,** latest time by which an activity has to be finished so as to not delay the completion time of the entire project

ST: **S**lack **T**ime**,** length of time an activity can be delayed without affecting the completion date for the entire project, computed as **ST = LS – ES = LF – EF**

CPM Steps and Rules

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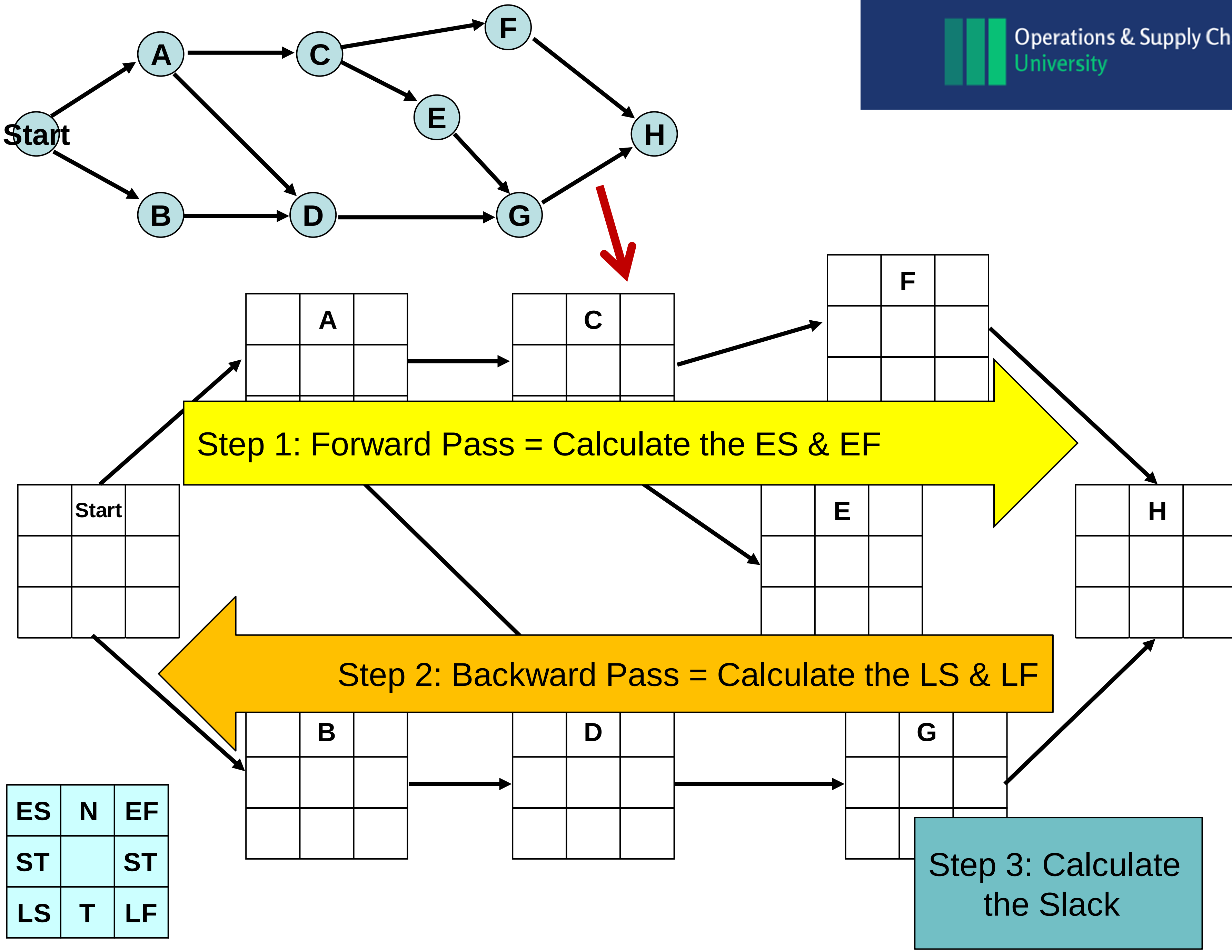
ES	N	EF
ST		ST
LS	T	LF

N: **Identification Number**
T: **Activity duration, Time to complete**
ES **Earliest Start**
EF **Earliest Finish**
LS **Latest Start**
LF: **Latest Finish**
ST: **Slack Time**

- Step 1: Forward pass: first ES = 0
  - Rule 1: EF = ES + T
  - Rule 2: the ES time for an activity equals the *largest* EF time of all immediate predecessors
- Step 2: Backward pass: first LF = last EF
  - Rule 3: LS = LF – T
  - Rule 4: the LF time for an activity equals the *smallest* LS time of all immediate successors
- Step 3: Calculate slack (ST = LS – ES = LF – EF) and critical path


Start
A
B
C
D
E
F
G
H
Step 1: Forward Pass = Calculate the ES & EF
Step 2: Backward Pass = Calculate the LS & LF
Step 3: Calculate the Slack
ES N EF
ST ST
LS T LF

Milwaukee Paper Example

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- Milwaukee Paper Manufacturing had long delayed the expense of installing advanced computerized air pollution control equipment in its facility
- When the Board of Directors adopted a new proactive policy on sustainability, it directed the plant manager to complete the installation in time for a major announcement of policy on Earth Day, 16 weeks away!
- Milwaukee Paper has identified 8 activities that need to be performed in order for the project to be completed
- See following table showing activity precedence relationships

- Task: Draw an AON network, compute earliest start and finish and latest start and finish times for each activity, calculate slack times, and determine critical path for the Milwaukee Paper project

Milwaukee Paper Project

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Activity	Description	Immediate Predecessors
A	Build internal components	-
B	Modify roof and floor	-
C	Construct collection stack	A
D	Pour concrete and install frame	A, B
E	Build high-temperature burner	C
F	Install pollution control system	C
G	Install air pollution device	D, E
H	Inspect and test	F, G

Milwaukee Paper Network Diagram (Activity on Node)

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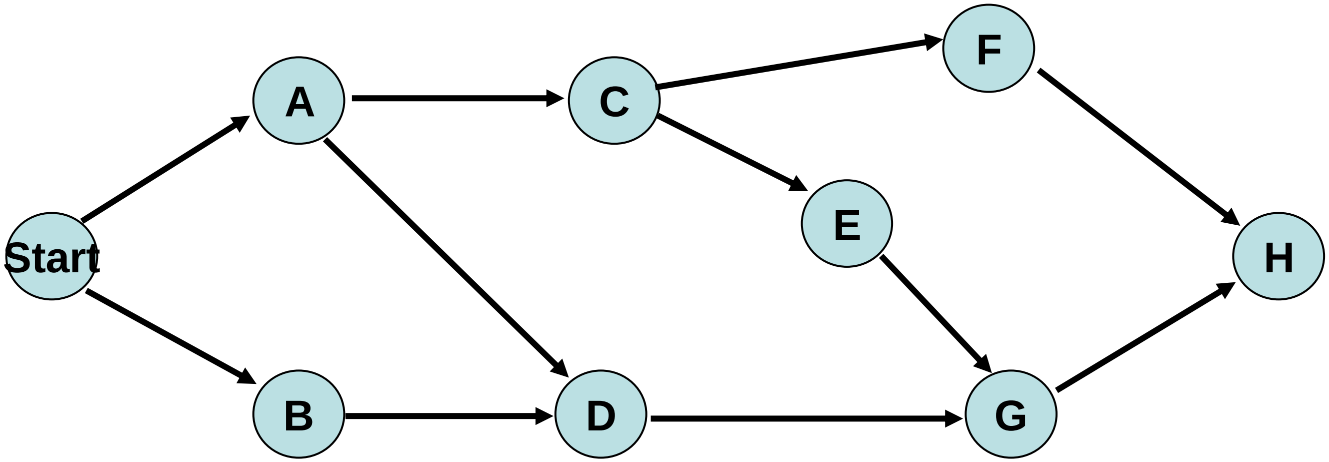
Activity	Description	Immediate Predecessors
A	Build internal components	-
B	Modify roof and floor	-
C	Construct collection stack	A
D	Pour concrete and install frame	A, B
E	Build high-temperature burner	C
F	Install pollution control system	C
G	Install air pollution device	D, E
H	Inspect and test	F, G



Milwaukee Paper Time Estimates

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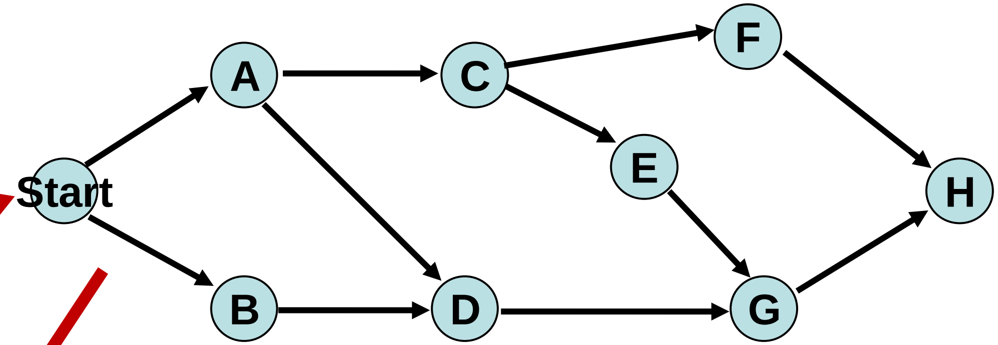
Activity	Description	Time (Weeks)
A	Build internal components	2
B	Modify roof and floor	3
C	Construct collection stack	2
D	Pour concrete and install frame	4
E	Build high-temperature burner	4
F	Install pollution control system	3
G	Install air pollution device	5
H	Inspect and test	2

Milwaukee Paper “Sudoku Squares”



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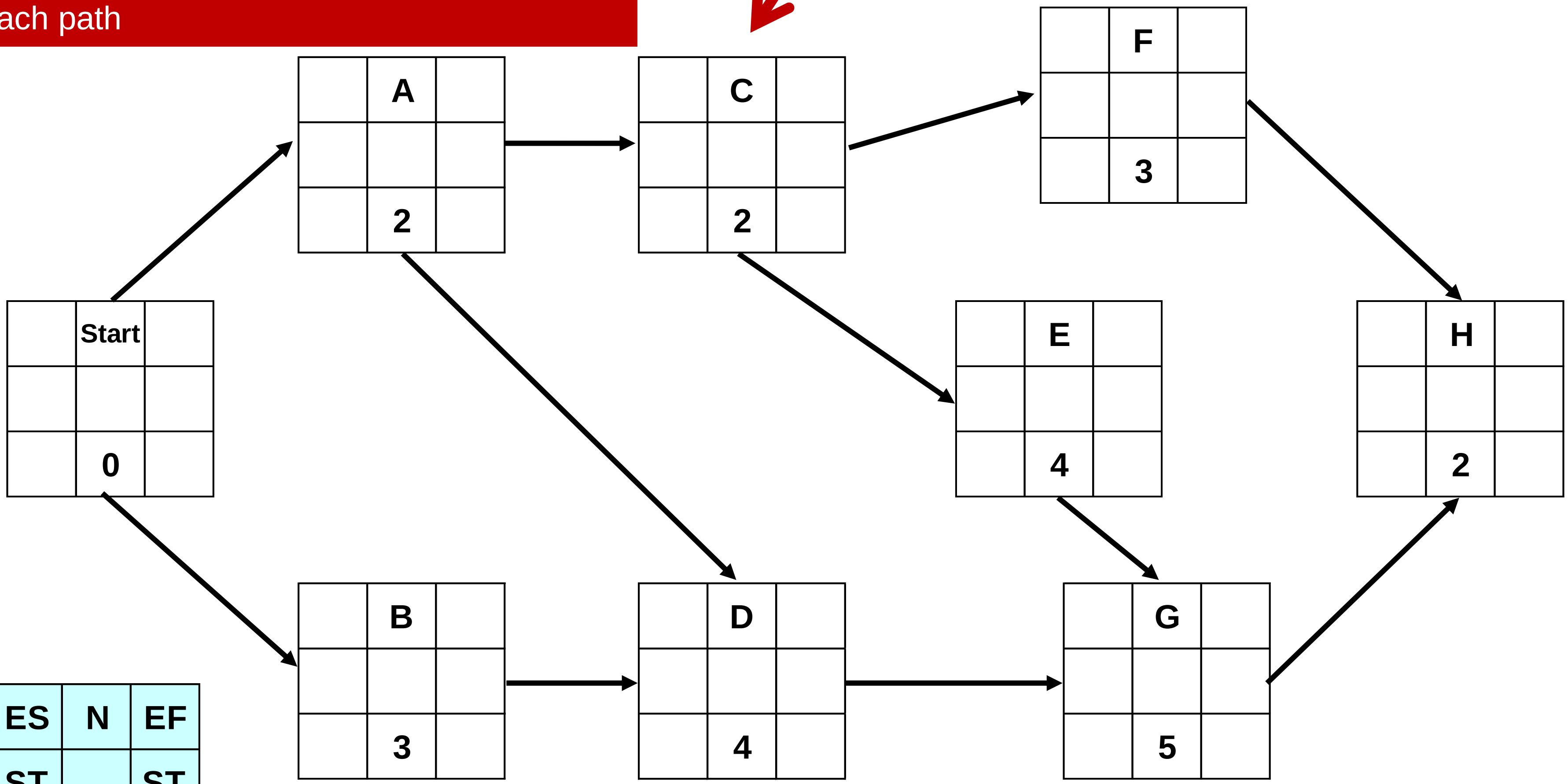

ES	N	EF
ST		ST
LS	T	LF

CPM Steps and Rules

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Milwaukee Paper Forward Pass

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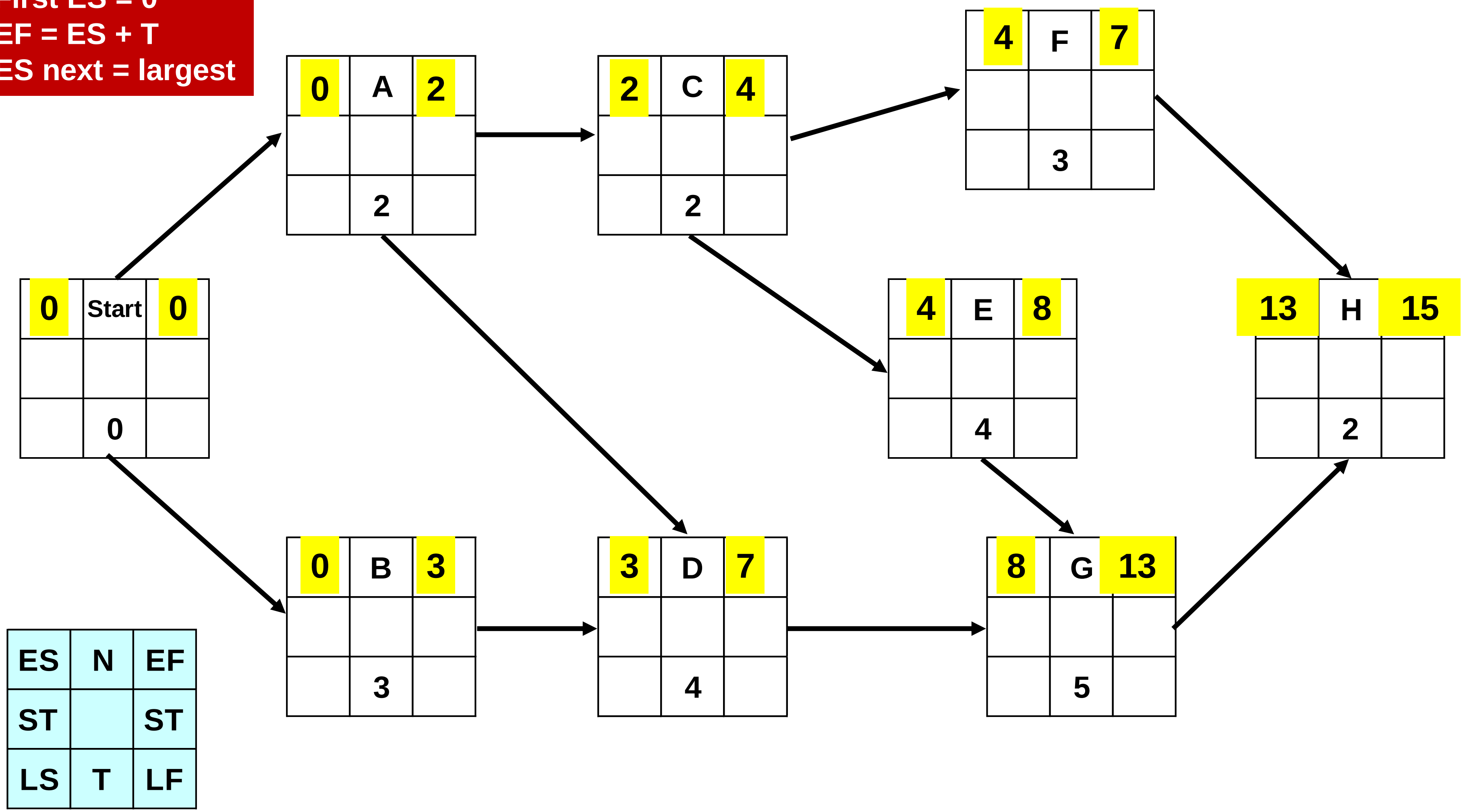
1. Forward pass:
First ES = 0
EF = ES + T
ES next = largest



CPM Steps and Rules

ES	N	EF
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Milwaukee Paper Backward Pass

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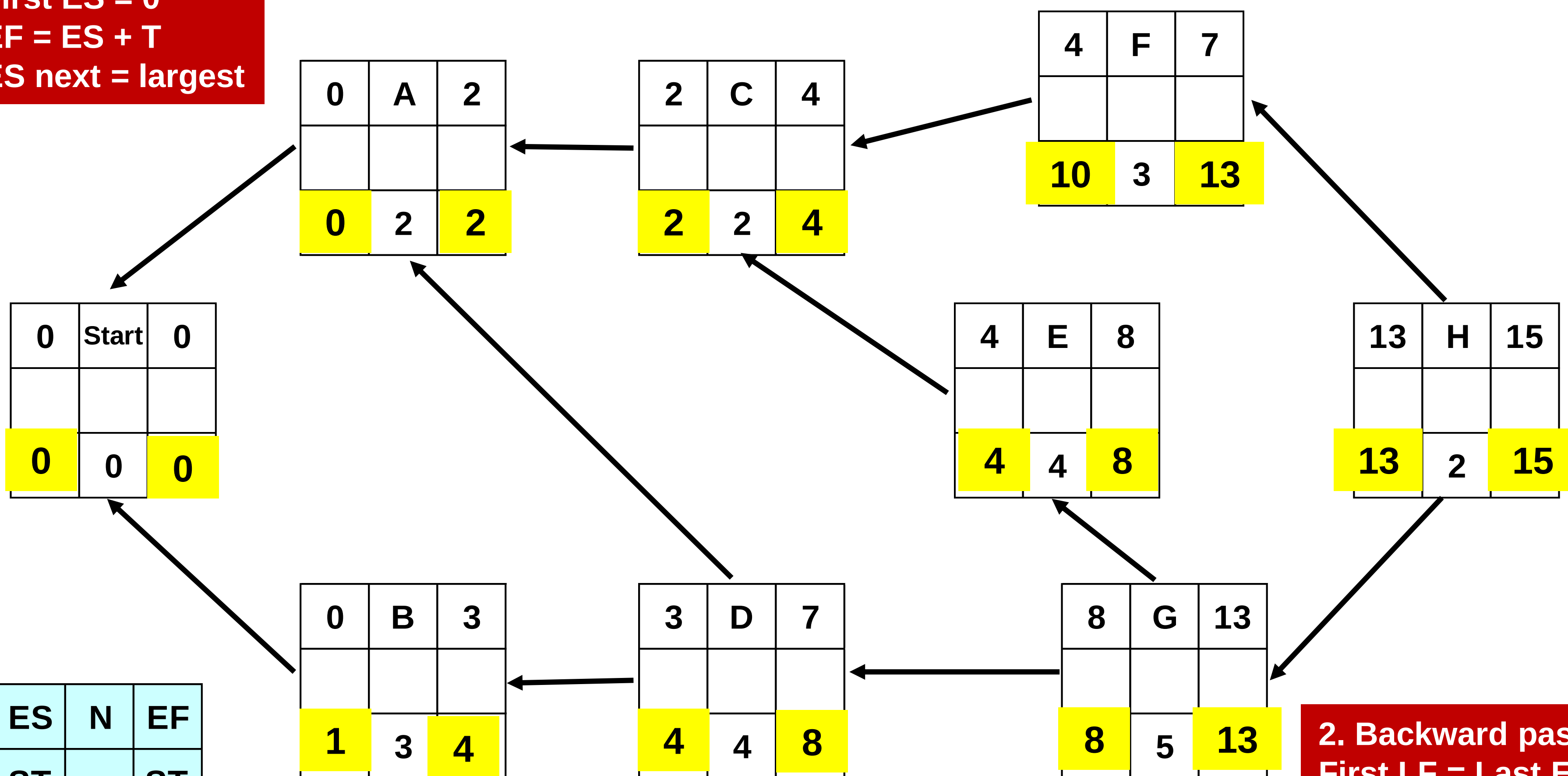
1. Forward pass:
First ES = 0
EF = ES + T
ES next = largest



ES	N	EF
ST		ST
LS	T	LF

2. Backward pass:
First LF = Last EF
LS = LF - T
LF next = smallest

CPM Steps and Rules

ES	N	EF
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LS	T	LF

N: **Identification Number**
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Milwaukee Paper Calculate Slack Time

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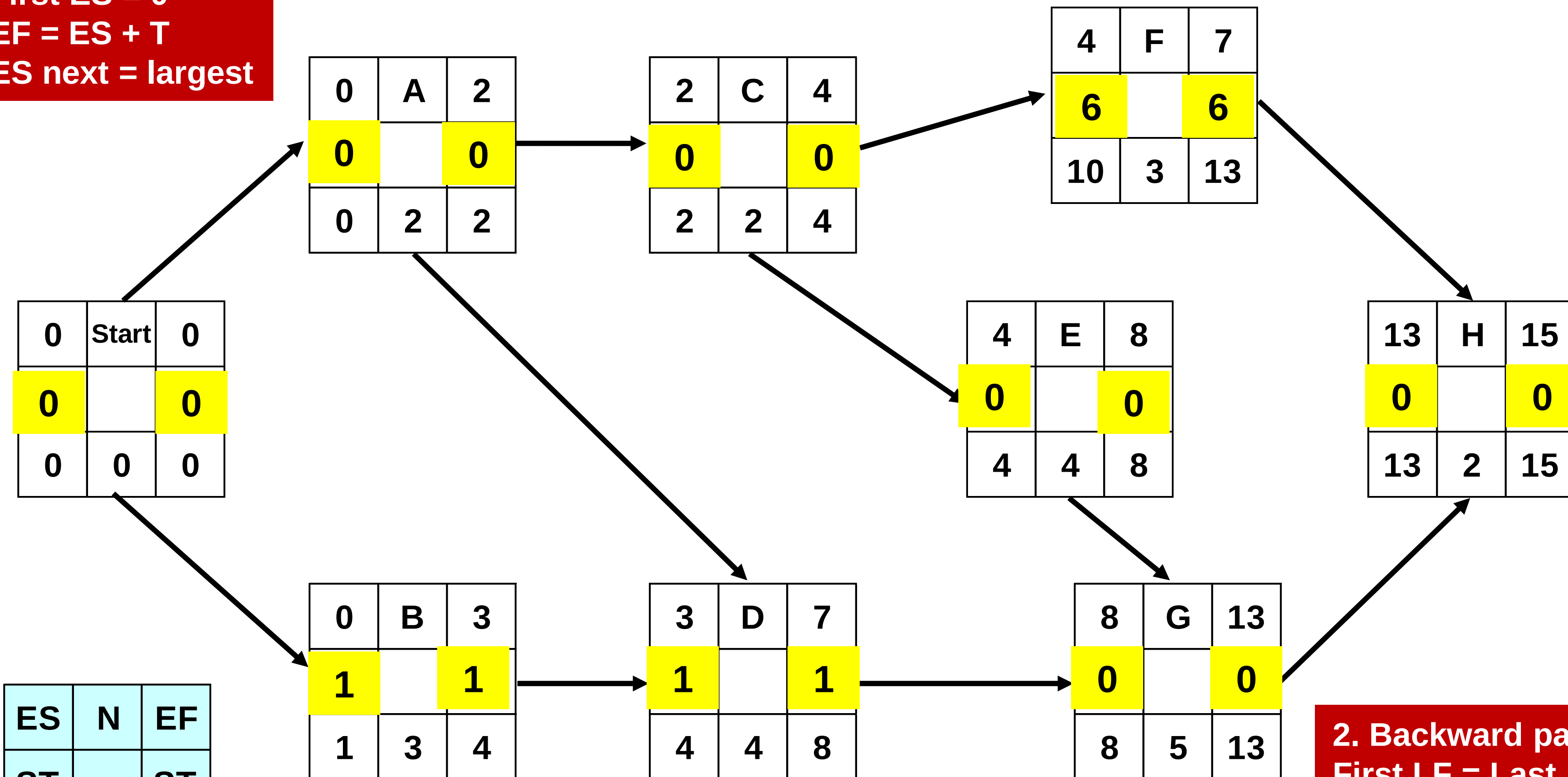
1. Forward pass:
First ES = 0
EF = ES + T
ES next = largest



ES	N	EF
ST		ST
LS	T	LF

2. Backward pass:
First LF = Last EF
LS = LF - T
LF next = smallest

3. Calculate slack
ST = LS – ES = LF - EF

Milwaukee Paper Determine Critical Path

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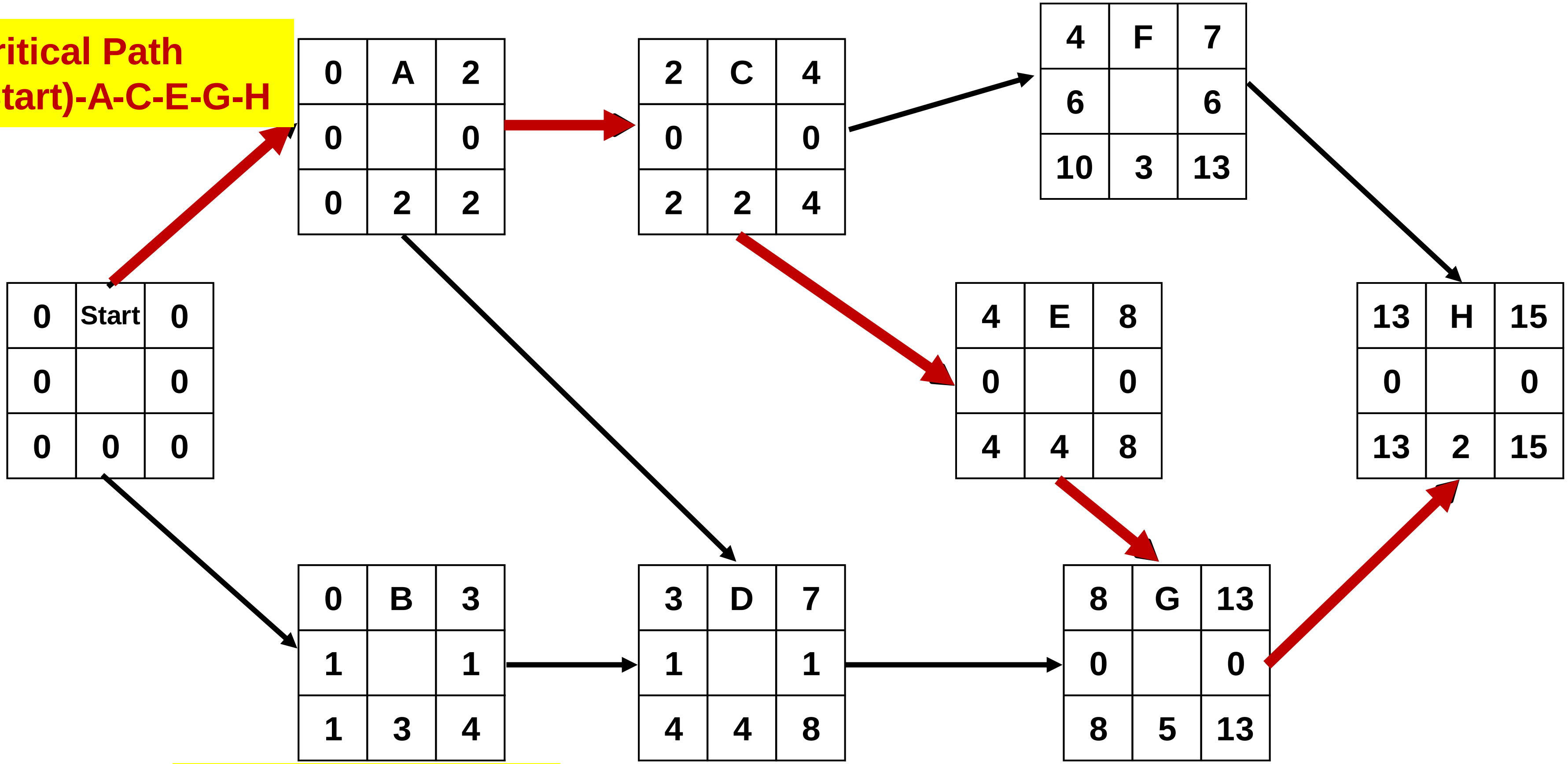
Critical Path
(Start)-A-C-E-G-H



<u>Multiple paths</u>:

(Start)-A-C-F-H = 0+2+2+3+2 = 9 weeks duration

(Start)-A-C-E-G-H = 0+2+2+4+5+2 = 15 weeks duration = Critical Path

(Start)-A-D-G-H = 0+2+4+5+2 = 13 weeks duration

(Start)-B-D-G-H = 0+3+4+5+2 = 14 weeks duration

Milwaukee Paper ES–EF Gantt Chart
(Critical Path in red)

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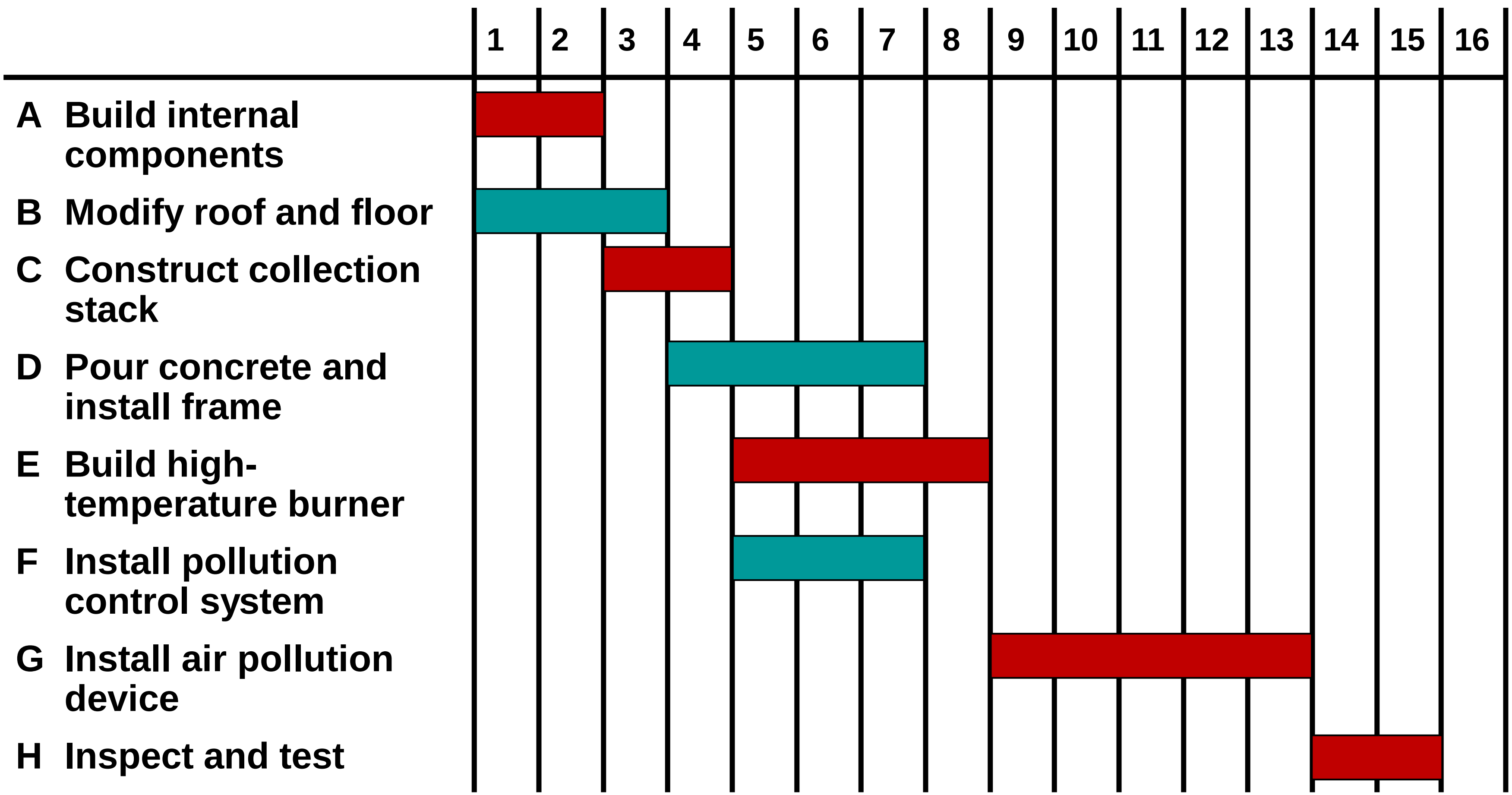

Milwaukee Paper ES–EF Gantt Chart
(Example of delay in completion of activity E)

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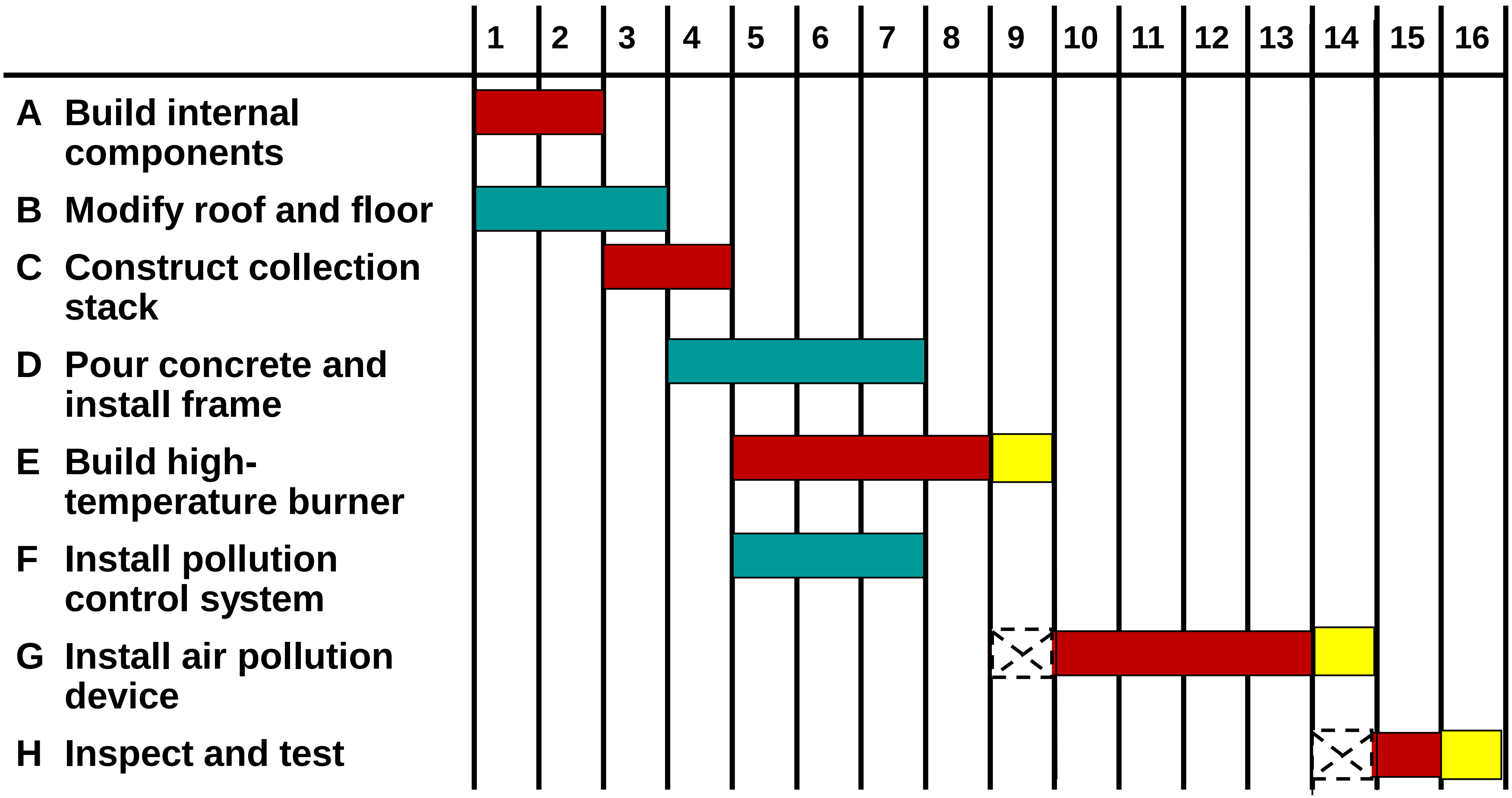

Variability in Activity Times

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- PERT (Project Evaluation and Review Technique) is another approach to project management
- PERT was developed to handle uncertainties and *variability* in activity completion times
  - In contrast, CPM assumes that activity times are *constant*
- Three PERT estimates are obtained for each activity:
  - Optimistic time (a): activity time under ideal conditions
  - Most likely time (m): most realistic activity time under normal conditions
  - Pessimistic time (b): activity time if breakdowns or serious delays occur
- Expected time (t): weighted average of three-time estimates

Variability in Activity Times

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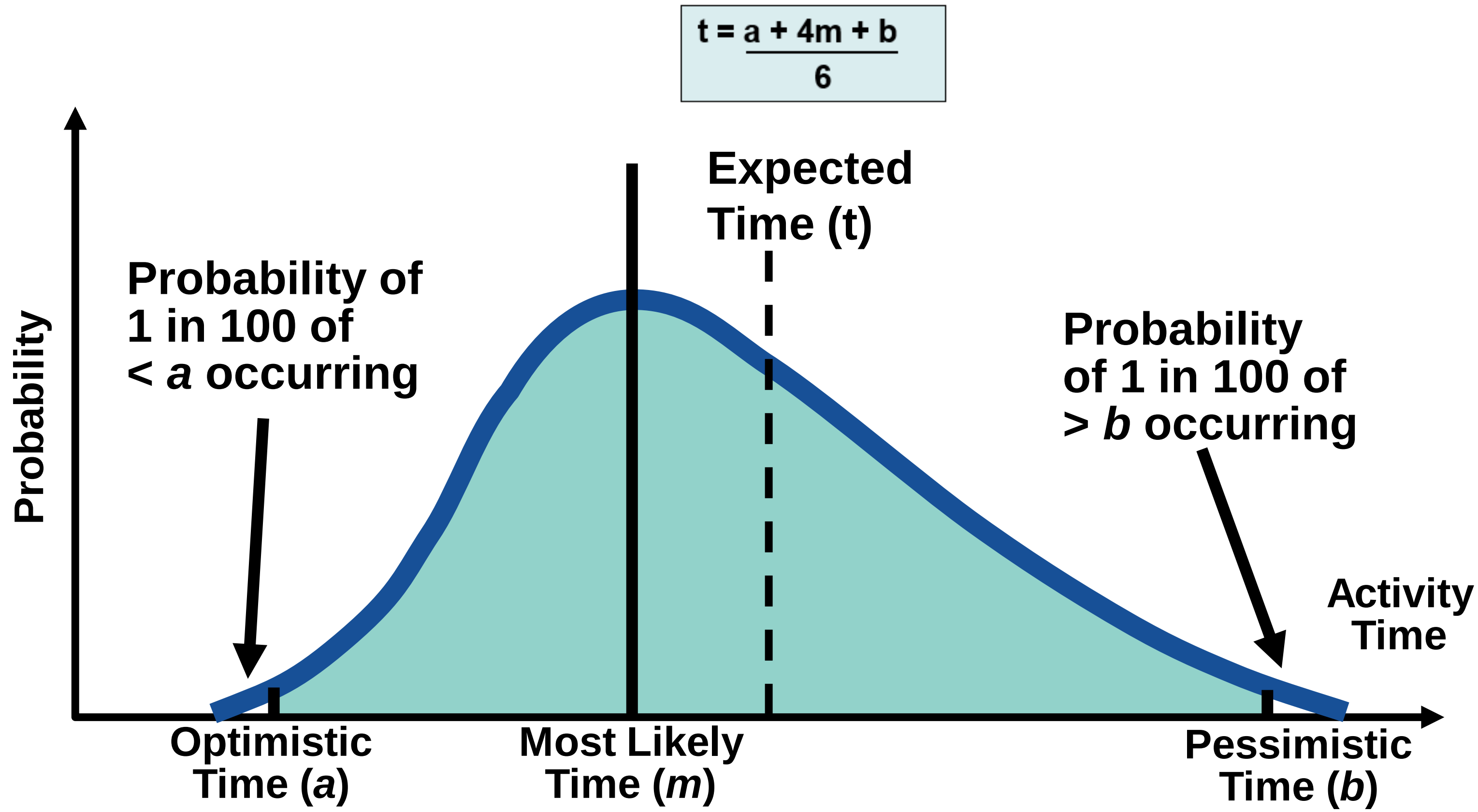
- Estimate follows beta distribution



Variability in Activity Times

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Expected time: $$t = \frac{1a + 4m + 1b}{6} \rightarrow t = \frac{a + 4m + b}{6}$$

Expected duration of a path:

Path duration = Σ of expected times of activities on the path

Variance of each activity: $$\sigma^2 = [(b - a)/6]^2$$

Standard deviation of path:

$$\sigma_{path} = \sqrt{\Sigma \text{ (Variances of activities on path)}}$$

And,

$$\sigma = \sqrt{\sigma^2}$$

Path Probabilities

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- PERT makes two more assumptions:
  - Total project completion times follow a normal probability distribution
  - Activity times are statistically independent
- The probability that a given path will be completed in a specified length of time:

$$z = \frac{\text{Specified time} - \text{Path duration}}{\text{Path standard deviation } (\sigma_{path})}$$

Note: $\sigma_{path} = \sqrt{\Sigma \text{ (Variances of activities on path)}}$

- z indicates how many standard deviations of the path distribution the specified time is beyond the expected path
- Rule of thumb: if the value of z is +3.00 or more, treat the probability of path completion by the specified time as 100%

Computing Expected Time (t) and Variance (σ^2)

Activity	Optimistic (a)	Most Likely (m)	Pessimistic (b)	Exp time (t) Calc	Expected time (t)	Variance Calc	Variance
A	1	2	3	$t_A = \frac{1 + 4(2) + 3}{6}$	2	$\sigma_A^2 = [(3-1) / 6]^2$	0.11
G	3	4	11				
H	1	2	3				

For Activity A: Expected time $= t = \frac{a + 4m + b}{6}$

$$t_A = \frac{1 + 4(2) + 3}{6} = \frac{12}{6} = 2$$

For Activity A: Variance $= \sigma^2 = [(b-a) / 6]^2$

$$\sigma_A^2 = [(3-1) / 6]^2 = 4/36 = 0.11$$

Take a moment, and solve for the Expected Time for and Variance for Activities G & H?

Computing Expected Time (t) and Variance (σ^2)

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Activity	Optimistic (a)	Most Likely (m)	Pessimistic (b)	Exp time (t) Calc	Expected time (t)	Variance Calc	Variance
A	1	2	3	$t_A = \frac{1 + 4(2) + 3}{6}$	2	$\sigma_A^2 = [(3-1) / 6]^2$	0.11
B	2	3	4	$t_B = \frac{2 + 4(3) + 4}{6}$	3	$\sigma_B^2 = [(4-2) / 6]^2$	0.11
C	1	2	3	$t_C = \frac{1 + 4(2) + 3}{6}$	2	$\sigma_C^2 = [(3-1) / 6]^2$	0.11
D	2	4	6	$t_D = \frac{2 + 4(4) + 6}{6}$	4	$\sigma_D^2 = [(6-2) / 6]^2$	0.44
E	1	4	7	$t_E = \frac{1 + 4(4) + 7}{6}$	4	$\sigma_E^2 = [(7-1) / 6]^2$	1.00
F	1	2	9	$t_F = \frac{1 + 4(2) + 9}{6}$	3	$\sigma_F^2 = [(9-1) / 6]^2$	1.78
G	3	4	11	$t_G = \frac{3 + 4(4) + 11}{6}$	5	$\sigma_G^2 = [(11-3) / 6]^2$	1.78
H	1	2	3	$t_H = \frac{1 + 4(2) + 3}{6}$	2	$\sigma_H^2 = [(3-1) / 6]^2$	0.11

Milwaukee Paper

- What is the probability this project can be completed on or before the 16-week deadline?

Activity	Optimistic (a)	Most Likely (m)	Pessimistic (b)	Expected time (t)	Variance
A	1	2	3	**2**	**0.11**
B	2	3	4	3	0.11
C	1	2	3	**2**	**0.11**
D	2	4	6	4	0.44
E	1	4	7	**4**	**1.00**
F	1	2	9	3	1.78
G	3	4	11	**5**	**1.78**
H	1	2	3	**2**	**0.11**

Critical path: (Start)-A-C-E-G-H

Expected duration = $\mathbf{t_A + t_C + t_E + t_G + t_H}$

$= 2 + 2 + 4 + 5 + 2 = 15$ weeks

Variance $= \boldsymbol{\sigma_A^2 + \sigma_C^2 + \sigma_E^2 + \sigma_G^2 + \sigma_H^2}$

$= 0.11 + 0.11 + 1.00 + 1.78 + 0.11 = 3.11$

Standard deviation $= \sigma_{path} = \sqrt{\boldsymbol{\sigma^2}} = \sqrt{3.11} = 1.76$

$$z = \frac{\text{Specified time} - \text{Path duration}}{\text{Path standard deviation}} = \frac{(16 \text{ weeks} - 15 \text{ weeks})}{1.76} = 0.57$$

Normal Curve Areas (Appendix I in textbook) Page A2

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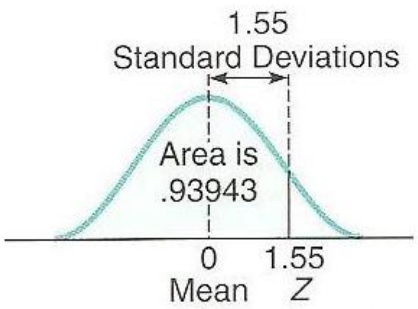
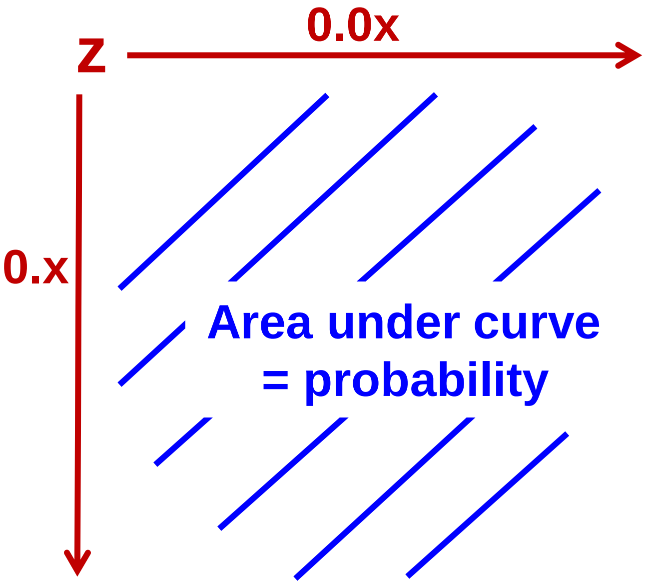
To find the area under the normal curve, you must know the how many standard deviations that point is to the right of the mean. Then, the area under the normal curve can be read directly from the table. For example, the total area under the normal curve for a point that is **1.55 standard deviations to the right of the mean is 0.93943** (x 100% = 93.94%)



How to use the chart:



*** Example Only - Not for Milwaukee Paper ***

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
.4	.65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670

Probability of Milwaukee Paper Project Completion in 16 Weeks

Operations & Supply Chain University

Use Appendix I to determine area under curve:

z = 0.57

Area = 0.7157

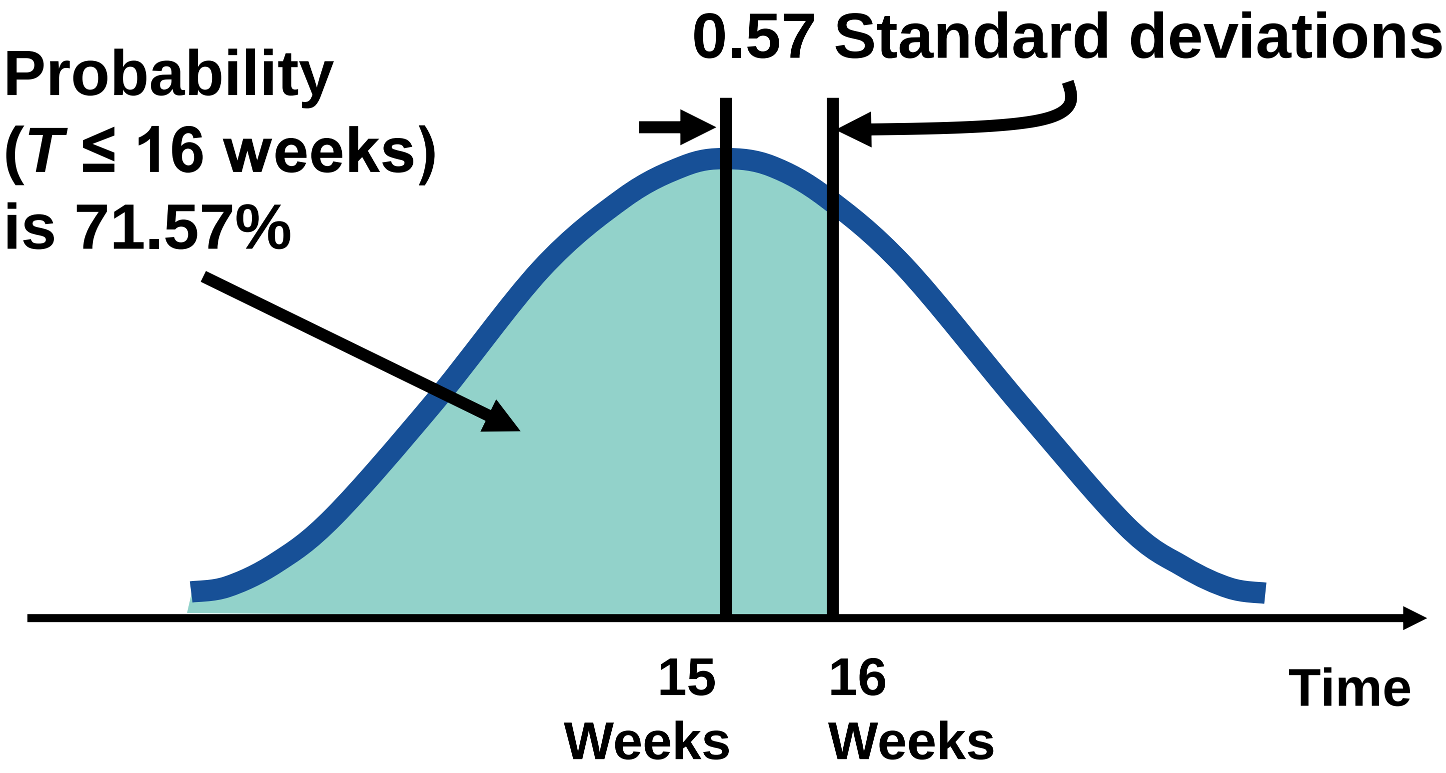
= 71.57%

TABLE I.1

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
.4	.65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97784	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158
2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
2.5	.99379	.99396	.99413	.99430	.99446	.99461	.99477	.99492	.99506	.99520
2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99609	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99899	.99893	.99896	.99900
3.1	.99903	.99906	.99910	.99913	.99916	.99918	.99921	.99924	.99926	.99929
3.2	.99931	.99934	.99936	.99938	.99940	.99942	.99944	.99946	.99948	.99950
3.3	.99952	.99953	.99955	.99957	.99958	.99960	.99961	.99962	.99964	.99965
3.4	.99966	.99968	.99969	.99970	.99971	.99972	.99973	.99974	.99975	.99976
3.5	.99977	.99978	.99978	.99979	.99980	.99981	.99981	.99982	.99983	.99983
3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989

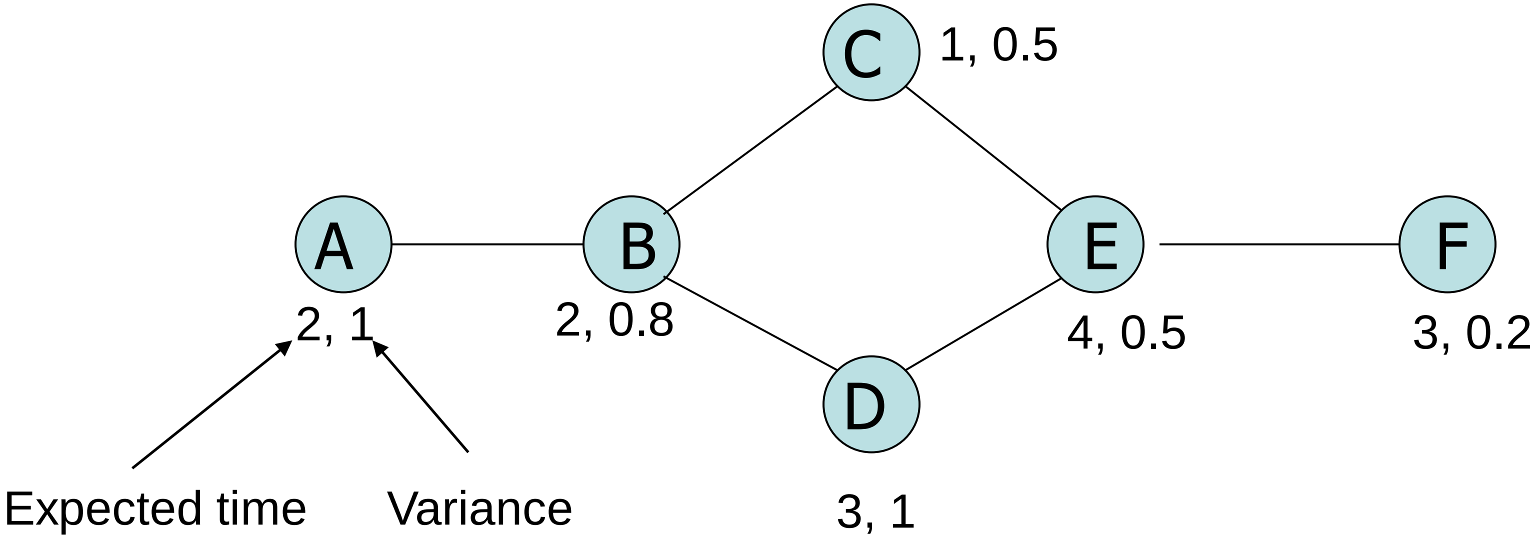
Probability of Milwaukee Paper Project Completion

Operations & Supply Chain University



PERT Example #2

Operations & Supply Chain University



1. What is the expected completion time and variance for this project?

Two paths: A-B-C-E-F = 2 + 2 + 1 + 4 + 3 = 12 days
A-B-D-E-F = 2 + 2 + 3 + 4 + 3 = 14 days

So the critical path is A-B-D-E-F

Variance = $\boldsymbol{\sigma_A^2 + \sigma_B^2 + \sigma_D^2 + \sigma_E^2 + \sigma_F^2 = 1.0 + 0.8 + 1.0 + 0.5 + 0.2 = 3.5}$

2. What is the probability that the project will meet a 12-day deadline?

Specified time = 12 days, Expected time = 14 days, Variance = 3.5 day
Z = (12 – 14)/sqrt(3.5) = -1.0689, look up area normal curve

PERT Example #2

Operations & Supply Chain University

Use Appendix I to determine the area under the curve (table values are for positive values of z). So, z = + 1.07 is 0.8577. However, since z has a negative sign, must subtract the area from 1 (for the remaining area)

Therefore, the probability of completing in 12 weeks (z = -1.07) = 1.00 – 0.8577 = 0.1423 or 14.23%

TABLE I.1

Z	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
.0	.50000	.50399	.50798	.51197	.51595	.51994	.52392	.52790	.53188	.53586
.1	.53983	.54380	.54776	.55172	.55567	.55962	.56356	.56749	.57142	.57535
.2	.57926	.58317	.58706	.59095	.59483	.59871	.60257	.60642	.61026	.61409
.3	.61791	.62172	.62552	.62930	.63307	.63683	.64058	.64431	.64803	.65173
.4	.65542	.65910	.66276	.66640	.67003	.67364	.67724	.68082	.68439	.68793
.5	.69146	.69497	.69847	.70194	.70540	.70884	.71226	.71566	.71904	.72240
.6	.72575	.72907	.73237	.73565	.73891	.74215	.74537	.74857	.75175	.75490
.7	.75804	.76115	.76424	.76730	.77035	.77337	.77637	.77935	.78230	.78524
.8	.78814	.79103	.79389	.79673	.79955	.80234	.80511	.80785	.81057	.81327
.9	.81594	.81859	.82121	.82381	.82639	.82894	.83147	.83398	.83646	.83891
1.0	.84134	.84375	.84614	.84849	.85083	.85314	.85543	.85769	.85993	.86214
1.1	.86433	.86650	.86864	.87076	.87286	.87493	.87698	.87900	.88100	.88298
1.2	.88493	.88686	.88877	.89065	.89251	.89435	.89617	.89796	.89973	.90147
1.3	.90320	.90490	.90658	.90824	.90988	.91149	.91309	.91466	.91621	.91774
1.4	.91924	.92073	.92220	.92364	.92507	.92647	.92785	.92922	.93056	.93189
1.5	.93319	.93448	.93574	.93699	.93822	.93943	.94062	.94179	.94295	.94408
1.6	.94520	.94630	.94738	.94845	.94950	.95053	.95154	.95254	.95352	.95449
1.7	.95543	.95637	.95728	.95818	.95907	.95994	.96080	.96164	.96246	.96327
1.8	.96407	.96485	.96562	.96638	.96712	.96784	.96856	.96926	.96995	.97062
1.9	.97128	.97193	.97257	.97320	.97381	.97441	.97500	.97558	.97615	.97670
2.0	.97725	.97784	.97831	.97882	.97932	.97982	.98030	.98077	.98124	.98169
2.1	.98214	.98257	.98300	.98341	.98382	.98422	.98461	.98500	.98537	.98574
2.2	.98610	.98645	.98679	.98713	.98745	.98778	.98809	.98840	.98870	.98899
2.3	.98928	.98956	.98983	.99010	.99036	.99061	.99086	.99111	.99134	.99158
2.4	.99180	.99202	.99224	.99245	.99266	.99286	.99305	.99324	.99343	.99361
2.5	.99379	.99396	.99413	.99430	.99446	.99461	.99477	.99492	.99506	.99520
2.6	.99534	.99547	.99560	.99573	.99585	.99598	.99609	.99621	.99632	.99643
2.7	.99653	.99664	.99674	.99683	.99693	.99702	.99711	.99720	.99728	.99736
2.8	.99744	.99752	.99760	.99767	.99774	.99781	.99788	.99795	.99801	.99807
2.9	.99813	.99819	.99825	.99831	.99836	.99841	.99846	.99851	.99856	.99861
3.0	.99865	.99869	.99874	.99878	.99882	.99886	.99899	.99893	.99896	.99900
3.1	.99903	.99906	.99910	.99913	.99916	.99918	.99921	.99924	.99926	.99929
3.2	.99931	.99934	.99936	.99938	.99940	.99942	.99944	.99946	.99948	.99950
3.3	.99952	.99953	.99955	.99957	.99958	.99960	.99961	.99962	.99964	.99965
3.4	.99966	.99968	.99969	.99970	.99971	.99972	.99973	.99974	.99975	.99976
3.5	.99977	.99978	.99978	.99979	.99980	.99981	.99981	.99982	.99983	.99983
3.6	.99984	.99985	.99985	.99986	.99986	.99987	.99987	.99988	.99988	.99989

Project Crashing

Operations & Supply Chain University

- Crashing a project refers to reducing the total time to complete the project to meet a revised due date
  - However, doing so has a cost – must evaluate the trade-offs between faster completion times and additional costs

- It is not uncommon to face the following situations:
  - The project is behind schedule
  - The completion time has been moved forward

- Factors to consider when crashing a project
  - You can only crash the permissible amount per activity
  - Taken together, the shortened activity durations will enable us to finish the project by the due date
  - The total cost of crashing is as small as possible

Project Crashing (examples)

Operations & Supply Chain University

- Hire additional resources (ex: from 2 laborers to 4)
  - Total labor cost increase from $2,000 to $4,000
  - May cut activity times in half

- Have employees work overtime (ex: from 40 hours a week to 50)
  - Weekly employee cost increase from $1,000 to $1,375
  - Would provide 25% more labor hours

- Pay expedite fees (ex: priority shipping of materials)
  - Shipping charge increase from $0 to $200
  - Inexpensive option to improve deliveries by a few days

- Hire additional contractors (ex: from 1 company to 2)
  - Total project cost from $10,000 to $20,000
  - Double the resources & costs!

Steps to Crash a Project

- Steps:
  1. Determine the crash cost per unit of time (period) for each activity. The only way to reduce project completion time is by reducing activities *on the critical path*
  2. If there is only one critical path, select the activity that has the smallest crash cost per period and crash this activity by *one period*. If there is more than one critical path, select one activity from each critical path such that total crash cost of *all activities* is smallest and crash each activity by one period.
  3. Update all activity times. If desired due date has been reached, *stop*. If not, repeat step 2.

Crashing

Operations & Supply Chain University

- Normal time (NT) = normal time to complete an activity
- Normal cost (NC) = normal cost to complete an activity
- Crash time (CT) = the shortest possible time the activity can realistically be completed
  - Some activities *cannot* be crashed due to the nature of the task
- Crash cost (CC) = the cost associated with completing an activity in its crash time rather than in its normal time

$$\text{Crash cost per unit of time} = \frac{CC - NC}{NT - CT}$$

Milwaukee Paper – Normal/Crash Costs and Time

Operations & Supply Chain University

Critical Path: A-C-E-G-H

Activity	Normal Time (Weeks)	Crash Time (Weeks)	Cost ($) Normal	Cost ($) Crash
A	2	1	22,000	22,750
B	3	1	30,000	34,000
C	2	1	26,000	27,000
D	4	3	48,000	49,000
E	4	2	56,000	58,000
F	3	2	30,000	30,500
G	5	2	80,000	84,500
H	2	1	16,000	19,000
		Total Project Cost:	$308,000	

Milwaukee Paper - Crashing

Activity	Normal Time (Weeks)	Crash Time (Weeks)	Cost ($) Normal	Cost ($) Crash	Calculation	Crash Cost per Week ($)	Number of Crash weeks
A	2	1	22,000	22,750	$\frac{22{,}750 - 22{,}000}{2-1}$	750	1
B	3	1	30,000	34,000	$\frac{34{,}000 - 30{,}000}{3-1}$	2,000	2
						,000	1
D	4	3	48,000	49,000		1,000	1
E	4	2	56,000	58,000		1,000	2
						500	1
G	5	2	80,000	84,500		1,500	3
H	2	1	16,000	19,000		3,000	1

Calculate crash cost per unit of time = CC – NC / NT – CT:
For Activity A = (22,750 – 22,000) / (2 – 1) = $750/1 week

For Activity B = (34,000 – 30,000) / (3 – 1) = $4000/2 week

Calculate crash cost per unit of time = CC – NC / NT – CT:
For Activity G & H?

Crash and Normal Times and Costs for Activity B

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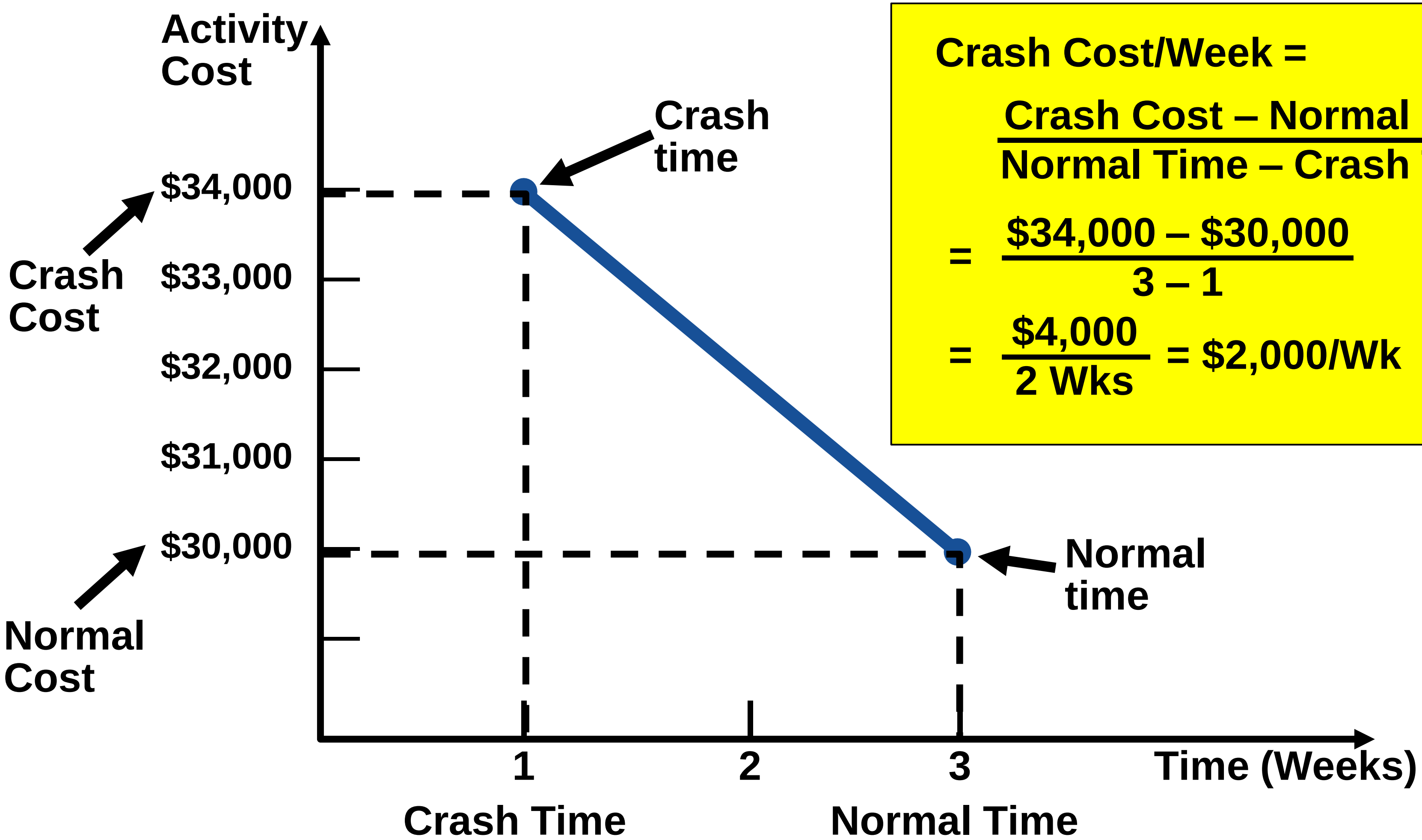


Crash Cost/Week =

$$\frac{\text{Crash Cost} - \text{Normal Cost}}{\text{Normal Time} - \text{Crash Time}}$$

$$= \frac{\$34{,}000 - \$30{,}000}{3 - 1}$$

$$= \frac{\$4{,}000}{2 \text{ Wks}} = \$2{,}000/\text{Wk}$$

Milwaukee Paper - Crashing

Operations & Supply Chain University

Critical Path: A-C-E-G-H

Activity	Normal Time (Weeks)	Crash Time (Weeks)	Cost ($) Normal	Cost ($) Crash	Crash Cost per Week ($)	Number of Crash weeks
A	2	1	22,000	22,750	750	1
B	3	1	30,000	34,000	2,000	2
C	2	1	26,000	27,000	1,000	1
D	4	3	48,000	49,000	1,000	1
E	4	2	56,000	58,000	1,000	2
F	3	2	30,000	30,500	500	1
G	5	2	80,000	84,500	1,500	3
H	2	1	16,000	19,000	3,000	1
		Total Project Cost:	**$308,000**			

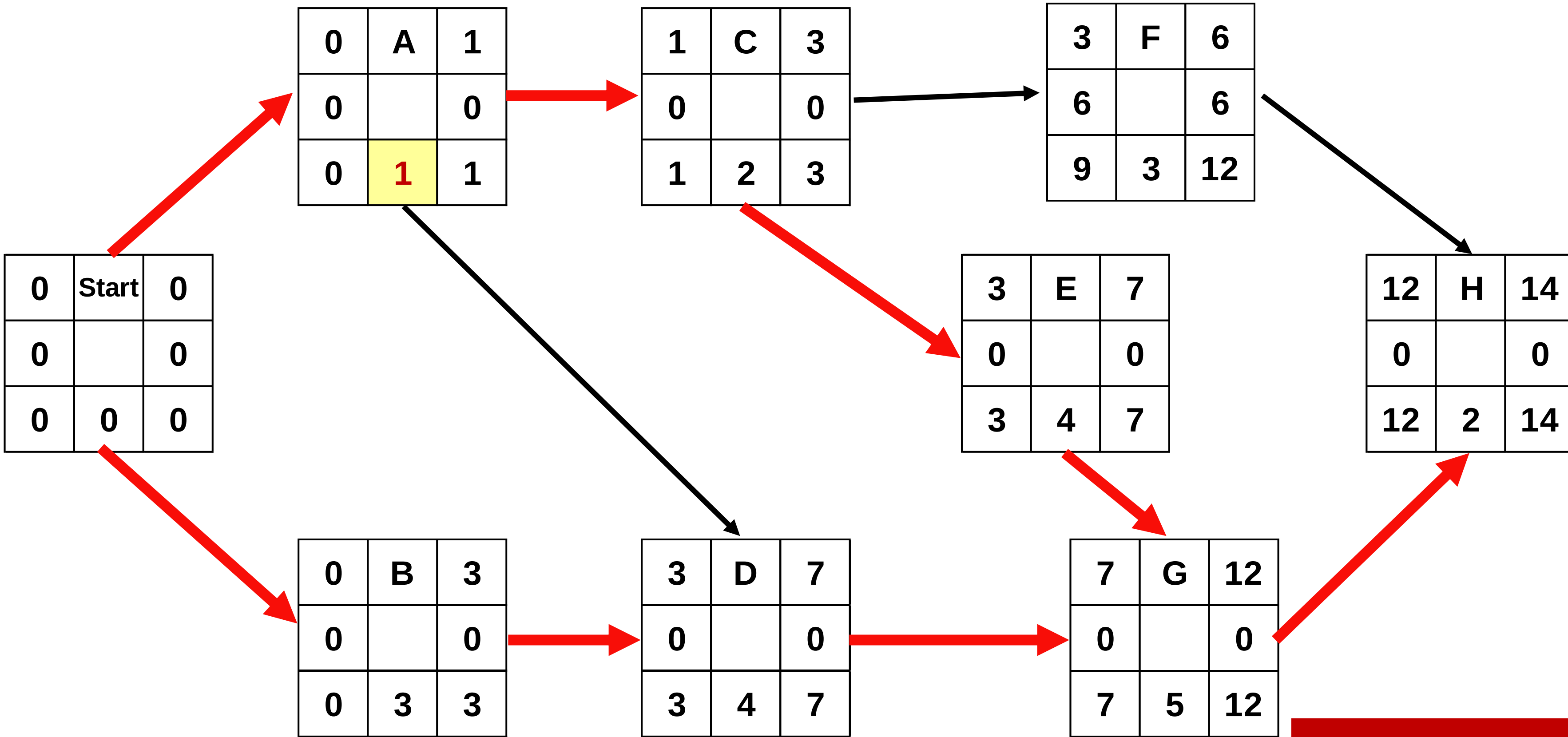
What to do to reduce the project by 1 week?

Option 1: crash activity F (at an incremental cost of $500) but not on CP

Option 2: crash activity A (at an incremental cost of $750)
Total project cost now $308,000 + 750 = $308,750, duration = 14 weeks

Milwaukee Paper (Crash 1 week A)

Operations & Supply Chain University



Now there are 2 Critical Paths!

<u>Multiple paths</u>:

Start-A-C-F-H = 0+1+2+3+2 = **8** weeks duration

Start-A-C-E-G-H = 0+1+2+4+5+2 = **14** weeks duration (critical path)

Start-A-D-G-H = 0+1+4+5+2 = **12** weeks duration

Start-B-D-G-H = 0+3+4+5+2 = **14** weeks duration (critical path)

Milwaukee Paper - Crashing

Operations & Supply Chain University

Critical Paths: A-C-E-G-H and B-D-G-H

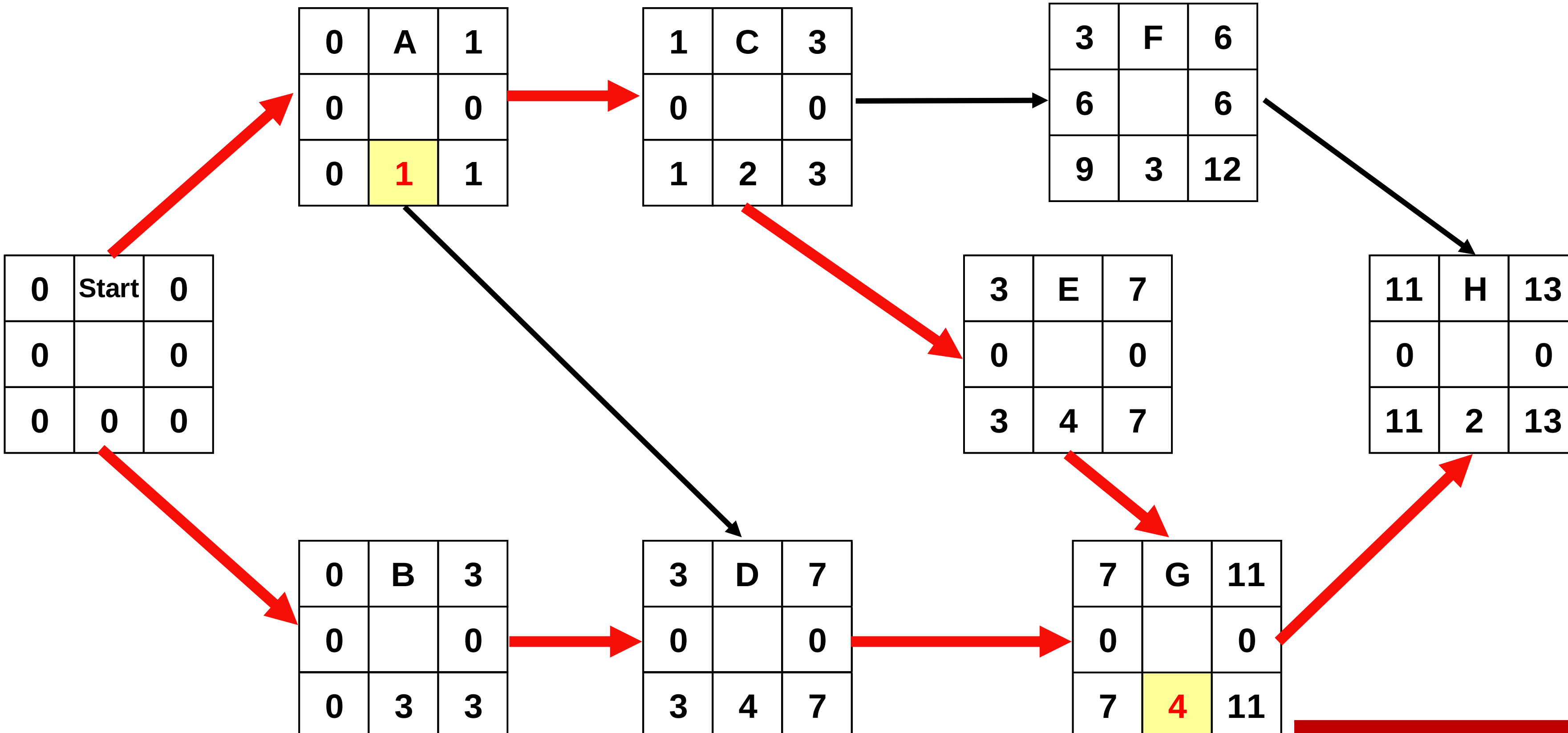
Activity	Normal Time (Weeks)	Crash Time (Weeks)	Cost ($) Normal	Cost ($) Crash	Crash Cost per Week ($)	Number of Crash weeks
A	2	1	22,000	22,750	750	1
B	3	1	30,000	34,000	2,000	2
C	2	1	26,000	27,000	1,000	1
D	4	3	48,000	49,000	1,000	1
E	4	2	56,000	58,000	1,000	2
F	3	2	30,000	30,500	500	1
G	5	2	80,000	84,500	1,500	3
H	2	1	16,000	19,000	3,000	1
		Crash one week:	**750**			
		Total Project Cost:	**$308,750**			

What to do to reduce the project by one more week?

Option 1: crash activity C (path Start-A-C-E-G-H, cost of $1,000)
crash activity D (path Start-B-D-G-H, cost of $1,000)
Total incremental cost $2,000

Option 2: crash activity G (common to both critical paths, cost of $1,500)
Total project cost now 308,750 + 1,500 = $310,250, duration = 13 weeks

Milwaukee Paper
(Crash 1 week A and G)



There are still 2 Critical Paths!

<u>Multiple paths</u>:

Start-A-C-F-H = 0+**1**+2+3+2 = **8** weeks duration

Start-A-C-E-G-H = 0+**1**+2+4+**4**+2 = **13** weeks duration (critical path)

Start-A-D-G-H = 0+**1**+**4**+5+2 = **11** weeks duration

Start-B-D-G-H = 0+3+4+**4**+2 = **13** weeks duration (critical path)

Milwaukee Paper - Crashing

Critical Paths: A-C-E-G-H and B-D-G-H

Activity	Normal Time (Weeks)	Crash Time (Weeks)	Cost ($) Normal	Cost ($) Crash	Crash Cost per Week ($)	Number of Crash weeks
A	2	1	22,000	22,750	750	1
B	3	1	30,000	34,000	2,000	2
C	2	1	26,000	27,000	1,000	1
D	4	3	48,000	49,000	1,000	1
E	4	2	56,000	58,000	1,000	2
F	3	2	30,000	30,500	500	1
G	5	2	80,000	84,500	1,500	3
H	2	1	16,000	19,000	3,000	1
		Crash two weeks:	**2,250**	**(=750 + 1500)**		
		Total Project Cost:	**$310,250**			

What to do to reduce the project by one more week?

Option 1: crash activity C (path Start-A-C-E-G-H, cost of $1,000)
crash activity D (path Start-B-D-G-H, cost of $1,000)
Total incremental cost $2,000

Option 2: crash activity G (common to both critical paths, cost of $1,500)
Total project cost now 310,250 + 1,500 = $311,750, duration = 12 weeks

Milwaukee Paper (Crash 1 wk A and 2 wks G)

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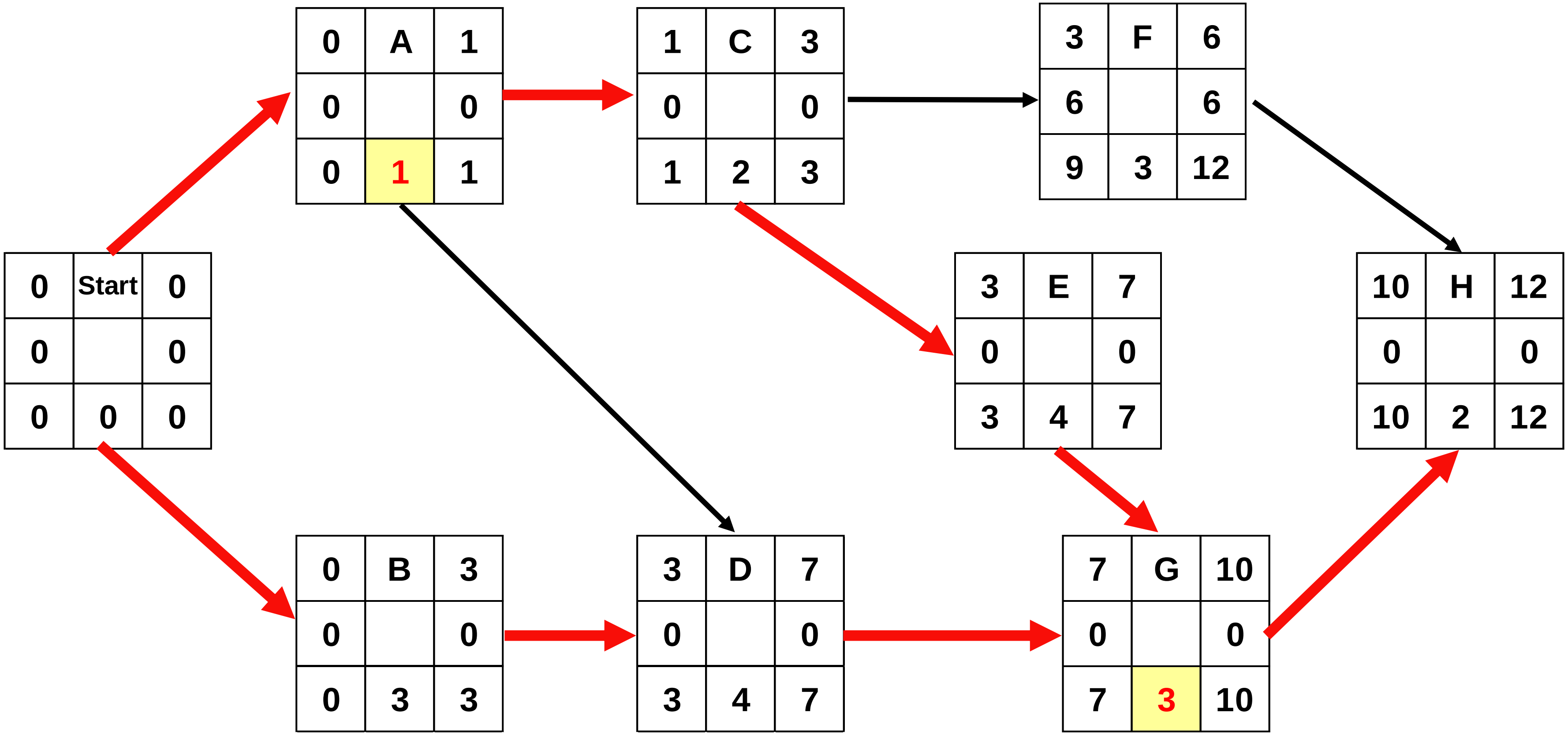

<u>Multiple paths</u>:

Start-A-C-F-H = 0+**1**+2+3+2 = **8** weeks duration

Start-A-C-E-G-H = 0+**1**+2+4+**3**+2 = **12** weeks duration (critical path)

Start-A-D-G-H = 0+**1**+4+**3**+2 = **10** weeks duration

Start-B-D-G-H = 0+3+4+**3**+2 = **12** weeks duration (critical path)

Project Risk Management

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- Risk: occurrence of events that have undesirable consequences
  - Delays
  - Increased costs
  - Inability to meet specifications
  - Project termination
- Risk Management
  - Identify potential risks
  - Analyze and assess risks
  - Work to minimize occurrence of risk
  - Establish contingency plans

Risk Event Probability and Cost

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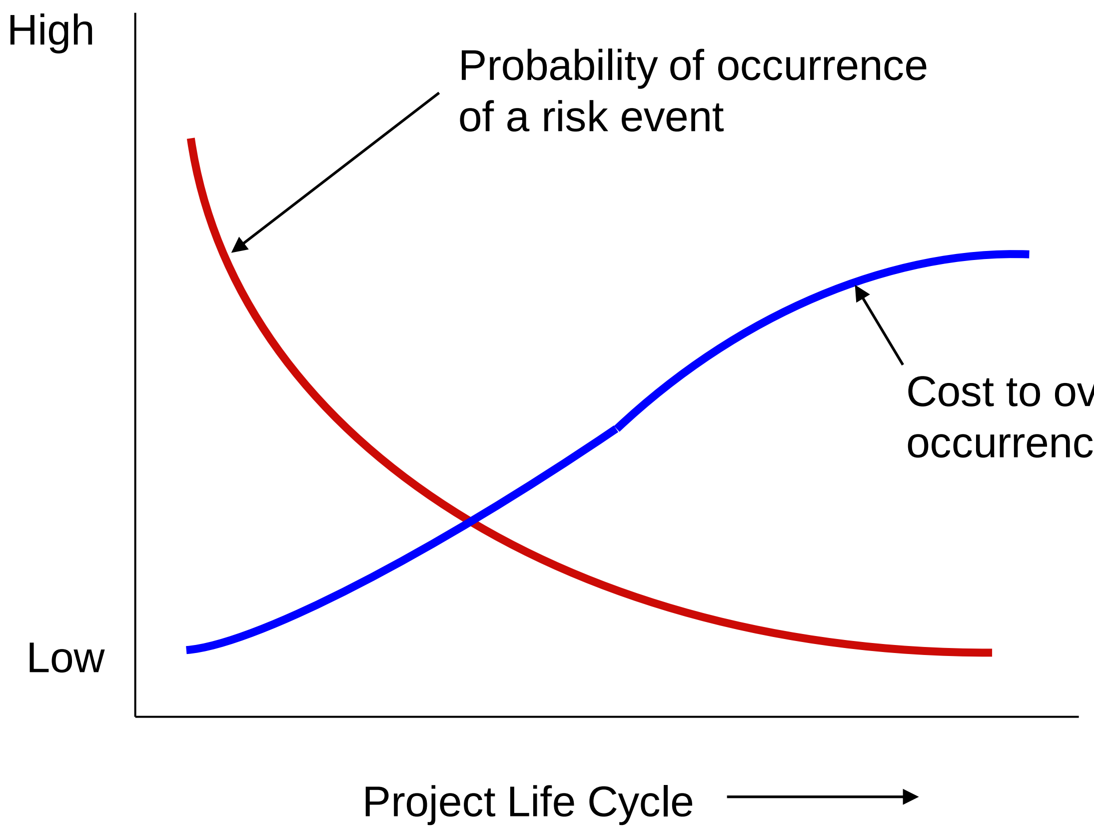

Project Management Information Systems

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- Managing Resources
  - In addition to scheduling each task, project managers must assign resources
  - Software can spot over-allocation (allocations exceed resources)
  - Must either add resources or reschedule
    - Moving a task within slack can free up resources

- Tracking Progress
  - Actual progress on a project will be different from the planned progress
    - Planned progress is called the *baseline*
  - A tracking Gantt chart superimposes the current schedule onto a baseline so deviations are visible
  - Project manager can then manage the deviations

Project Management Information Systems

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Project Management Software:

- Microsoft Project (Microsoft)
- Oracle Primavera (Oracle)
- MindView (Match Ware)
- HP Project (Hewlett-Packard)
- Fast Track (AEC Software)

Advantages of PM Software:

- Imposes a methodology
- Provides logical planning structure
- Enhances team communication
- Flag constraint violations
- Automatic report formats
- Multiple levels of reports
- Enables what-if scenarios
- Generates various chart types

Microsoft Project Example

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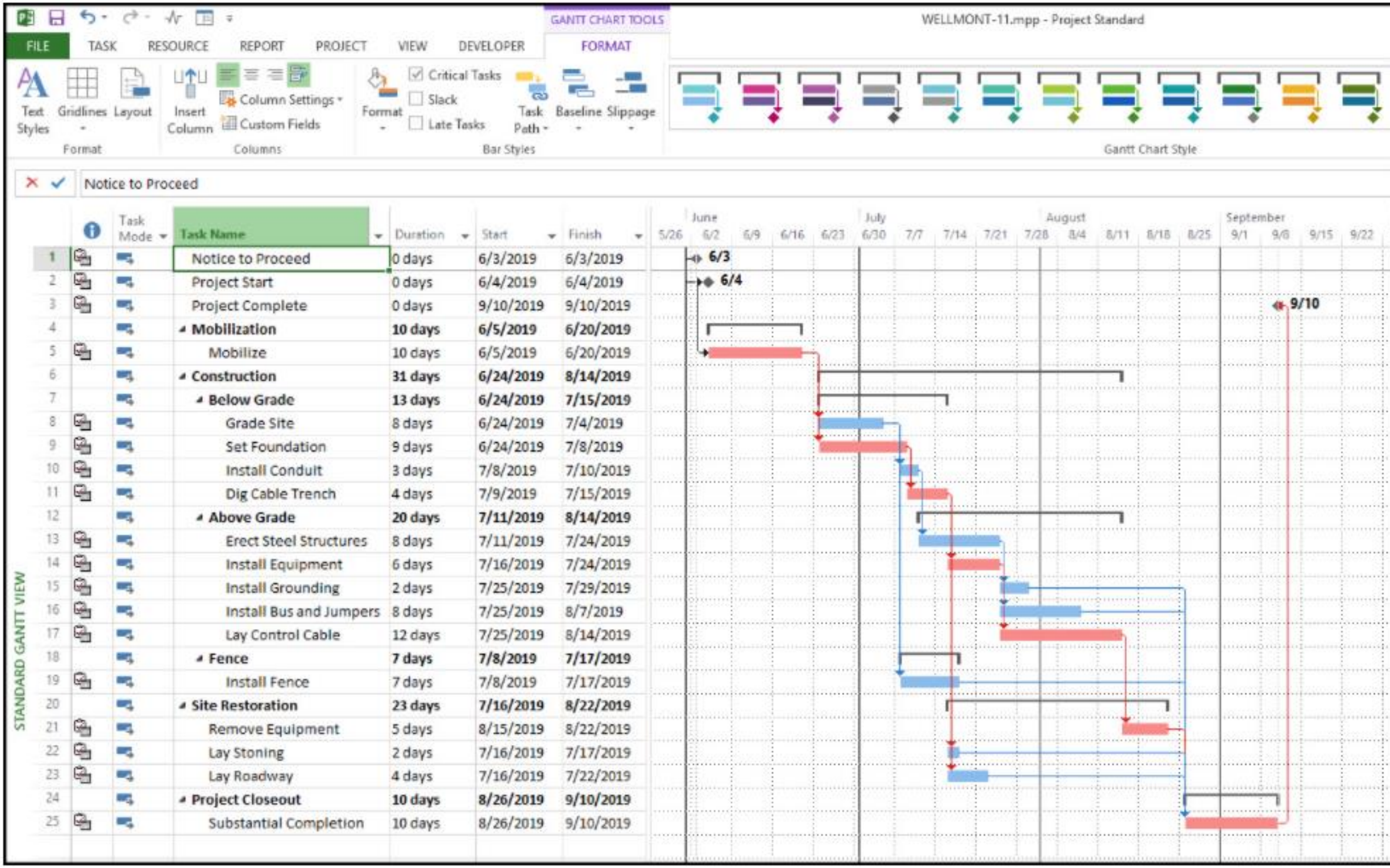

	Task Name	Duration	Start	Finish
1	Notice to Proceed	0 days	6/3/2019	6/3/2019
2	Project Start	0 days	6/4/2019	6/4/2019
3	Project Complete	0 days	9/10/2019	9/10/2019
4	**Mobilization**	**10 days**	**6/5/2019**	**6/20/2019**
5	Mobilize	10 days	6/5/2019	6/20/2019
6	**Construction**	**31 days**	**6/24/2019**	**8/14/2019**
7	**Below Grade**	**13 days**	**6/24/2019**	**7/15/2019**
8	Grade Site	8 days	6/24/2019	7/4/2019
9	Set Foundation	9 days	6/24/2019	7/8/2019
10	Install Conduit	3 days	7/8/2019	7/10/2019
11	Dig Cable Trench	4 days	7/9/2019	7/15/2019
12	**Above Grade**	**20 days**	**7/11/2019**	**8/14/2019**
13	Erect Steel Structures	8 days	7/11/2019	7/24/2019
14	Install Equipment	6 days	7/16/2019	7/24/2019
15	Install Grounding	2 days	7/25/2019	7/29/2019
16	Install Bus and Jumpers	8 days	7/25/2019	8/7/2019
17	Lay Control Cable	12 days	7/25/2019	8/14/2019
18	**Fence**	**7 days**	**7/8/2019**	**7/17/2019**
19	Install Fence	7 days	7/8/2019	7/17/2019
20	**Site Restoration**	**23 days**	**7/16/2019**	**8/22/2019**
21	Remove Equipment	5 days	8/15/2019	8/22/2019
22	Lay Stoning	2 days	7/16/2019	7/17/2019
23	Lay Roadway	4 days	7/16/2019	7/22/2019
24	**Project Closeout**	**10 days**	**8/26/2019**	**9/10/2019**
25	Substantial Completion	10 days	8/26/2019	9/10/2019