Chapter 12

Project Management

To accompany
Quantitative Analysis for Management, Eleventh Edition,
by Render, Stair, and Hanna
Power Point slides created by Brian Peterson

Learning Objectives

After completing this chapter, students will be able to:

1. Understand how to plan, monitor, and control projects with the use of PERT and CPM.
2. Determine earliest start, earliest finish, latest start, latest finish, and slack times for each activity, along with the total project completion time.
3. Reduce total project time at the least total cost by crashing the network using manual or linear programming techniques.
4. Understand the important role of software in project management.

Chapter Outline

Introduction

- Managing large-scale, complicated projects effectively is a difficult problem and the stakes are high.
- The first step in planning and scheduling a project is to develop the ***work breakdown structure.***
- Time, cost, resource requirements, predecessors, and people required are identified for each activity.
- A schedule for the project then can be developed.

Introduction

- The ***program evaluation and review technique*** (***PERT***) and the ***critical path method*** (***CPM***) are two popular quantitative analysis techniques to help plan, schedule, monitor, and control projects.
- Originally the approaches differed in how they estimated activity times.
  - PERT used three time estimates to develop a probabilistic estimate of completion time.
  - CPM was a more deterministic technique.
- They have become so similar they are commonly considered one technique, PERT/CPM.

Six Steps of PERT/CPM

1. Define the project and all of its significant activities or tasks.
2. Develop the relationships among the activities and decide which activities must precede 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.

The critical path is important since any delay in these activities can delay the completion of the project.

PERT/CPM

Given the large number of tasks in a project, it is easy to see why the following questions are important:

1. When will the entire project be completed?
2. What are the *critical* activities or tasks in the project, that is, the ones that will delay the entire project if they are late?
3. Which are the *non-critical* activities, that is, the ones that can run late without delaying the entire project's completion?
4. If there are three time estimates, what is the probability that the project will be completed by a specific date?

PERT/CPM

5. At any particular date, is the project on schedule, behind schedule, or ahead of schedule?
6. On any given date, is the money spent equal to, less than, or greater than the budgeted amount?
7. Are there enough resources available to finish the project on time?

General Foundry Example of PERT/CPM

- General Foundry, Inc. has long been trying to avoid the expense of installing air pollution control equipment.
- The local environmental protection group has recently given the foundry 16 weeks to install a complex air filter system on its main smokestack.
- General Foundry was warned that it will be forced to close unless the device is installed in the allotted period.
- They want to make sure that installation of the filtering system progresses smoothly and on time.

General Foundry Example of PERT/CPM

Activities and immediate predecessors for General Foundry

ACTIVITY	DESCRIPTION	IMMEDIATE PREDECESSORS
A	Build internal components	—
B	Modify roof and floor	—
C	Construct collection stack	*A*
D	Pour concrete and install frame	*B*
E	Build high-temperature burner	*C*
F	Install control system	*C*
G	Install air pollution device	*D*, *E*
H	Inspect and test	*F*, *G*

Table 12.1

Drawing the PERT/CPM Network

- There are two common techniques for drawing PERT networks.
- ***Activity-on-node*** (***AON***) where the nodes represent activities.
- ***Activity-on-arc*** (***AOA***) where the arcs are used to represent the activities.
- The AON approach is easier and more commonly found in software packages.
- One node represents the start of the project, one node for the end of the project, and nodes for each of the activities.
- The arcs are used to show the predecessors for each activity.

General Foundry Example of PERT/CPM

Network for General Foundry

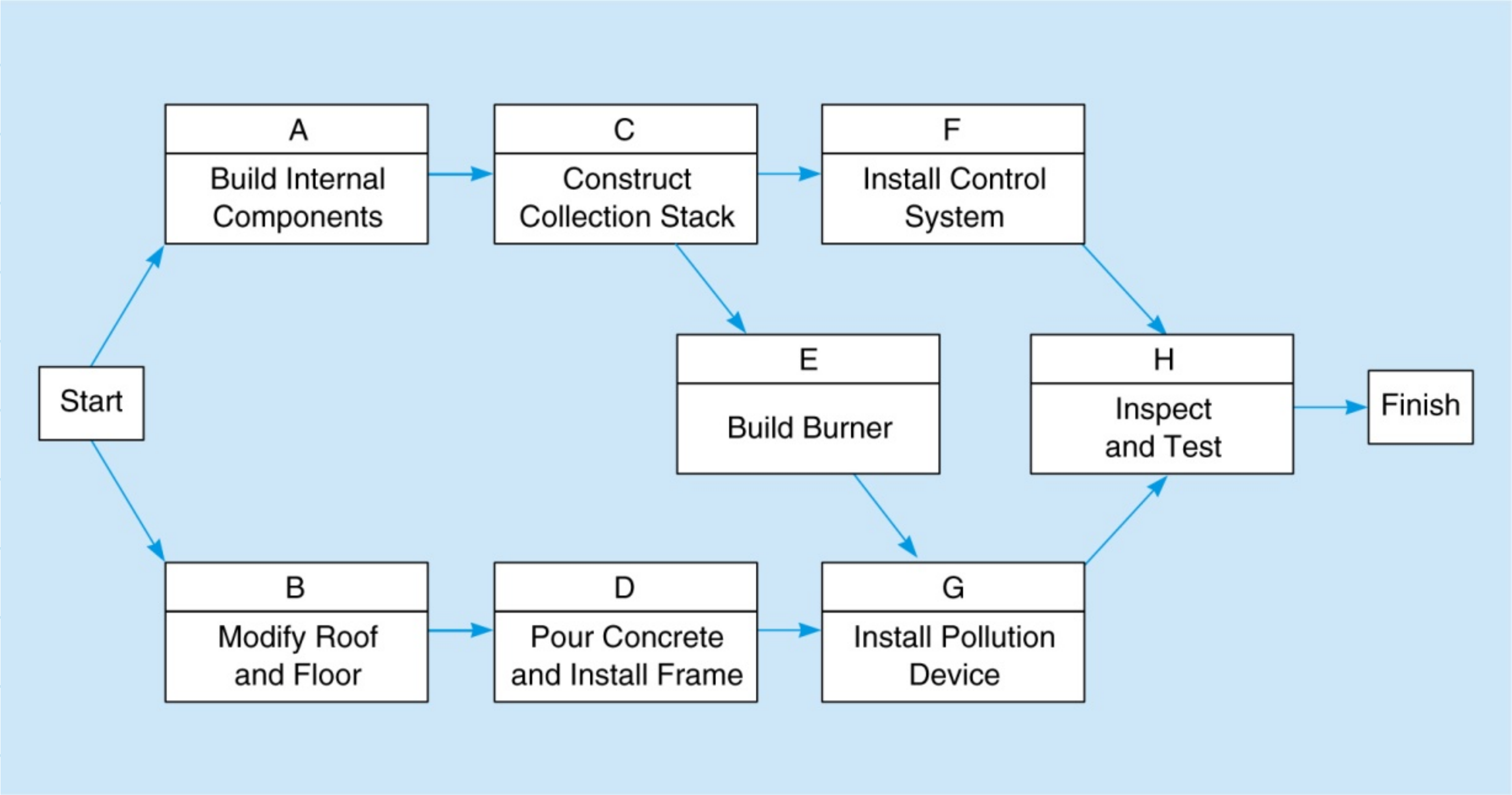


Figure 12.1

Activity Times

- In some situations, activity times are known with certainty.
- The CPM assigns just one time estimate to each activity and this is used to find the critical path.
- In many projects there is uncertainty about activity times.
- PERT employs a probability distribution based on three time estimates for each activity, and a weighted average of these estimates is used for the time estimate and this is used to determine the critical path.
  - PERT often assumes time estimates follow a ***beta probability distribution***.

Activity Times

The time estimates in PERT are:

Optimistic time (a) = time an activity will take if everything goes as well as possible. There should be only a small probability (say, $^{1}/_{100}$) of this occurring.

Pessimistic time (b) = time an activity would take assuming very unfavorable conditions. There should also be only a small probability that the activity will really take this long.

Most likely time (m) = most realistic time estimate to complete the activity

Activity Times

Beta Probability Distribution with Three Time Estimates

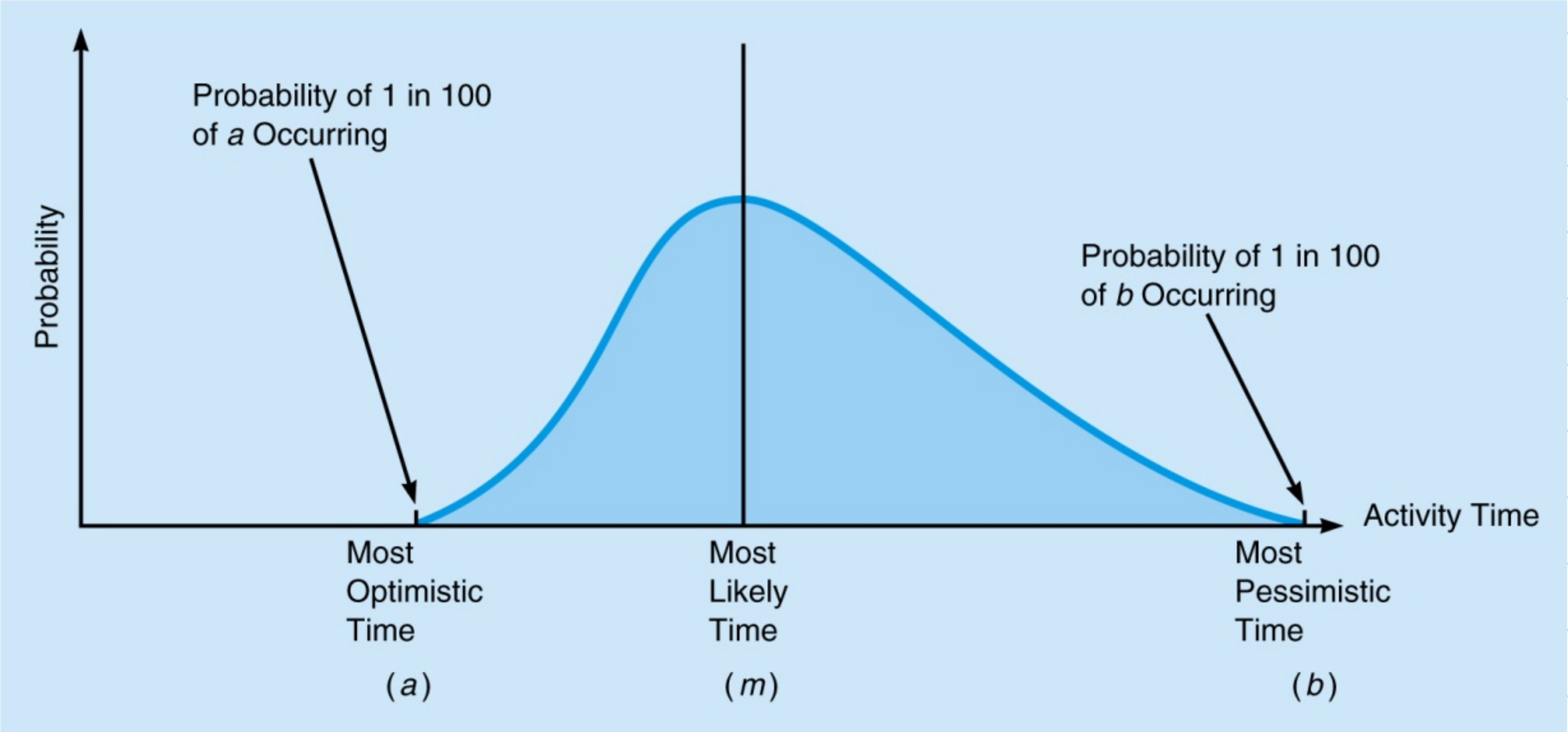


Figure 12.2

Activity Times

To find the ***expected activity time*** (*t*), the beta distribution weights the estimates as follows:

$$t = \frac{a + 4m + b}{6}$$

To compute the dispersion or ***variance of activity completion time***, we use the formula:

$$\text{Variance} = \left(\frac{b - a}{6}\right)^2$$

Activity Times

Time estimates (weeks) for General Foundry

ACTIVITY	OPTIMISTIC, a	MOST PROBABLE, m	PESSIMISTIC, b	EXPECTED TIME, $t = [(a + 4m + b)/6]$	VARIANCE, $[(b - a)/6]^2$
A	1	2	3	2	4/36
B	2	3	4	3	4/36
C	1	2	3	2	4/36
D	2	4	6	4	16/36
E	1	4	7	4	36/36
F	1	2	9	3	64/36
G	3	4	11	5	64/36
H	1	2	3	2	4/36
				25	

Table 12.2

How to Find the Critical Path

- **We accept the expected completion time for each task as the actual time for now.**
- **The total of 25 weeks in Table 12.2 does not take into account the obvious fact that some of the tasks could be taking place at the same time.**
- **To find out how long the project will take we perform the critical path analysis for the network.**
- **The *critical path* is the longest path through the network.**

How to Find the Critical Path

General Foundry's Network With Expected Activity Times

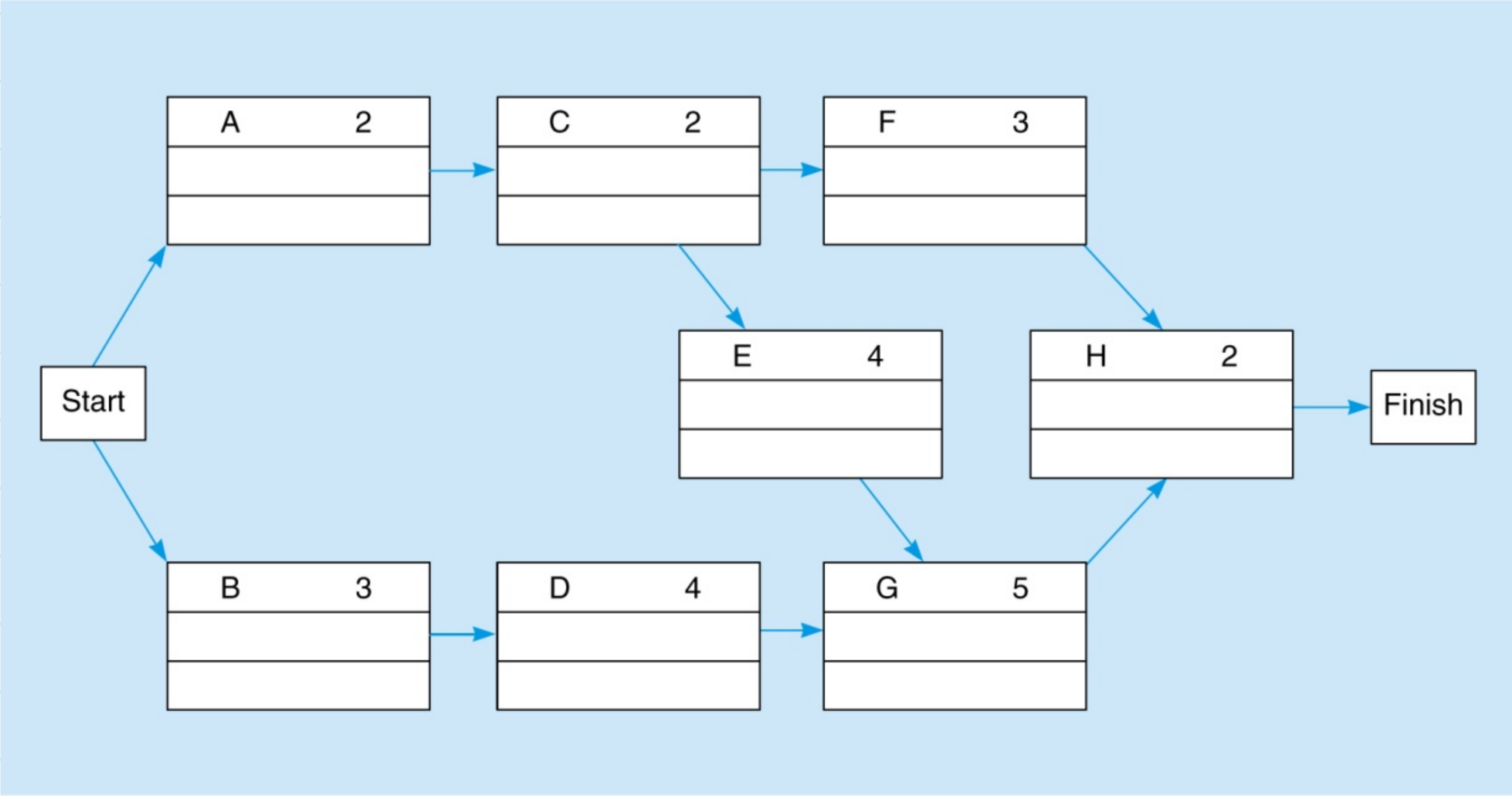


Figure 12.3

How to Find the Critical Path

To find the critical path, we need to determine the following quantities for each activity in the network.

1. ***Earliest start time*** (***ES***): the earliest time an activity can begin without violation of immediate predecessor requirements.
2. ***Earliest finish time*** (***EF***): the earliest time at which an activity can end.
3. ***Latest start time*** (***LS***): the latest time an activity can begin without delaying the entire project.
4. ***Latest finish time*** (***LF***): the latest time an activity can end without delaying the entire project.

How to Find the Critical Path

In the nodes, the activity time and the early and late start and finish times are represented in the following manner.

ACTIVITY	t
ES	EF
LS	LF

Earliest times are computed as:

Earliest finish time = Earliest start time + Expected activity time

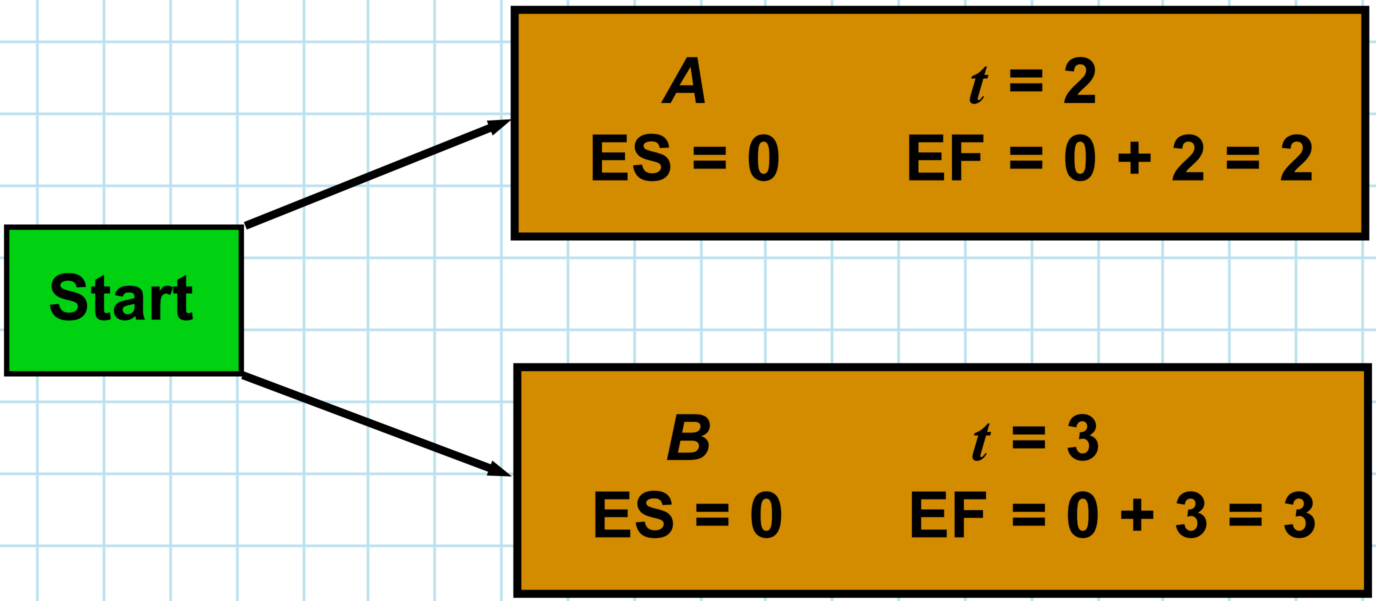
$$EF = ES + t$$

Earliest start = Largest of the earliest finish times of immediate predecessors

ES = Largest EF of immediate predecessors

How to Find the Critical Path

- At the start of the project we set the time to zero.
- Thus ES = 0 for both *A* and *B.*



How to Find the Critical Path

General Foundry's Earliest Start (ES) and Earliest Finish (EF) times

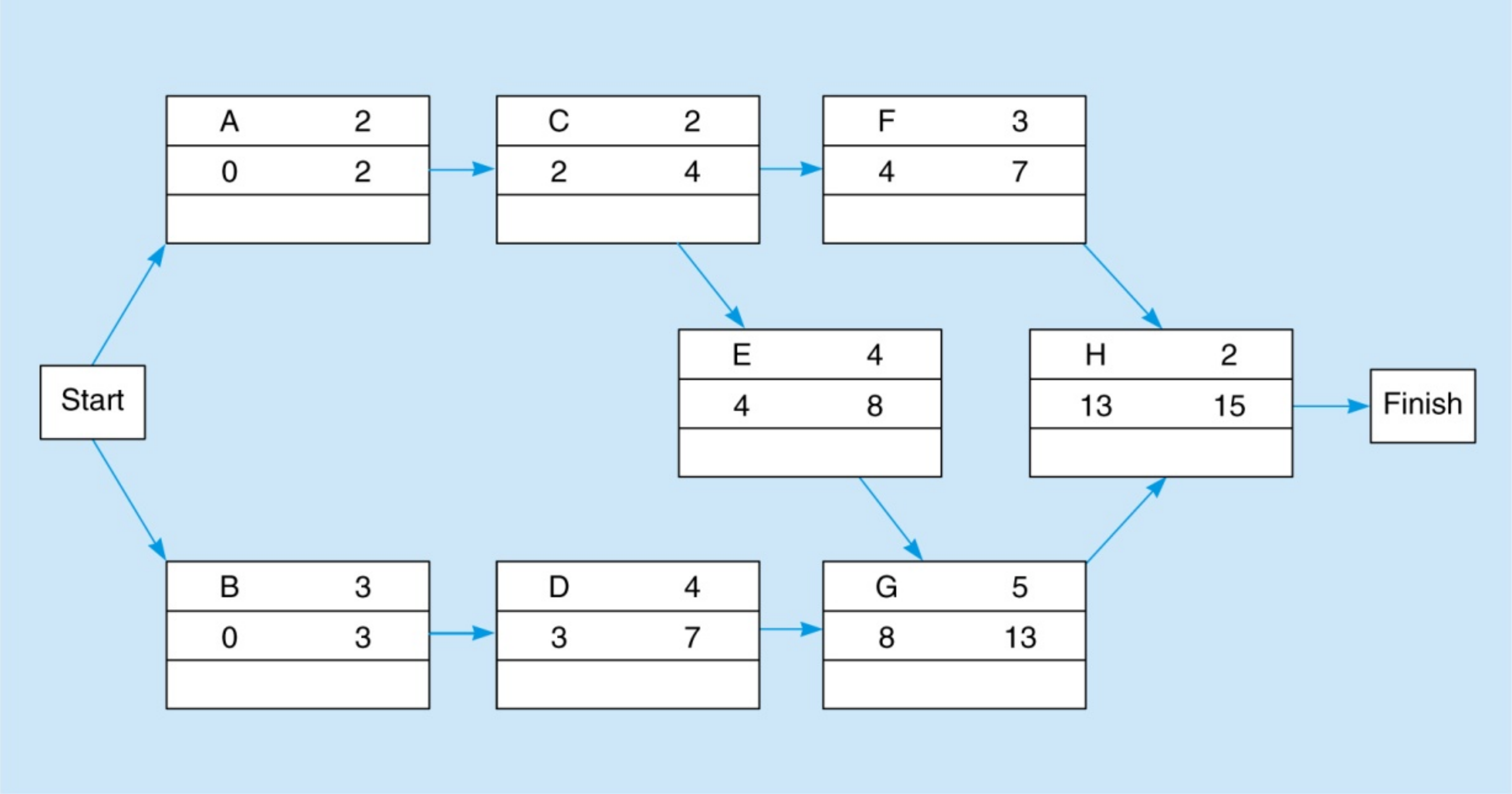


Figure 12.4

How to Find the Critical Path

Latest times are computed as

Latest start time = Latest finish time
– Expected activity time

$$\text{LS} = \text{LF} - t$$

Latest finish time = Smallest of latest start times for following activities

LF = Smallest LS of following activities

For activity *H:*

$$\text{LS} = \text{LF} - t = 15 - 2 = 13 \text{ weeks}$$

How to Find the Critical Path

General Foundry's Latest Start (LS) and Latest Finish (LF) times

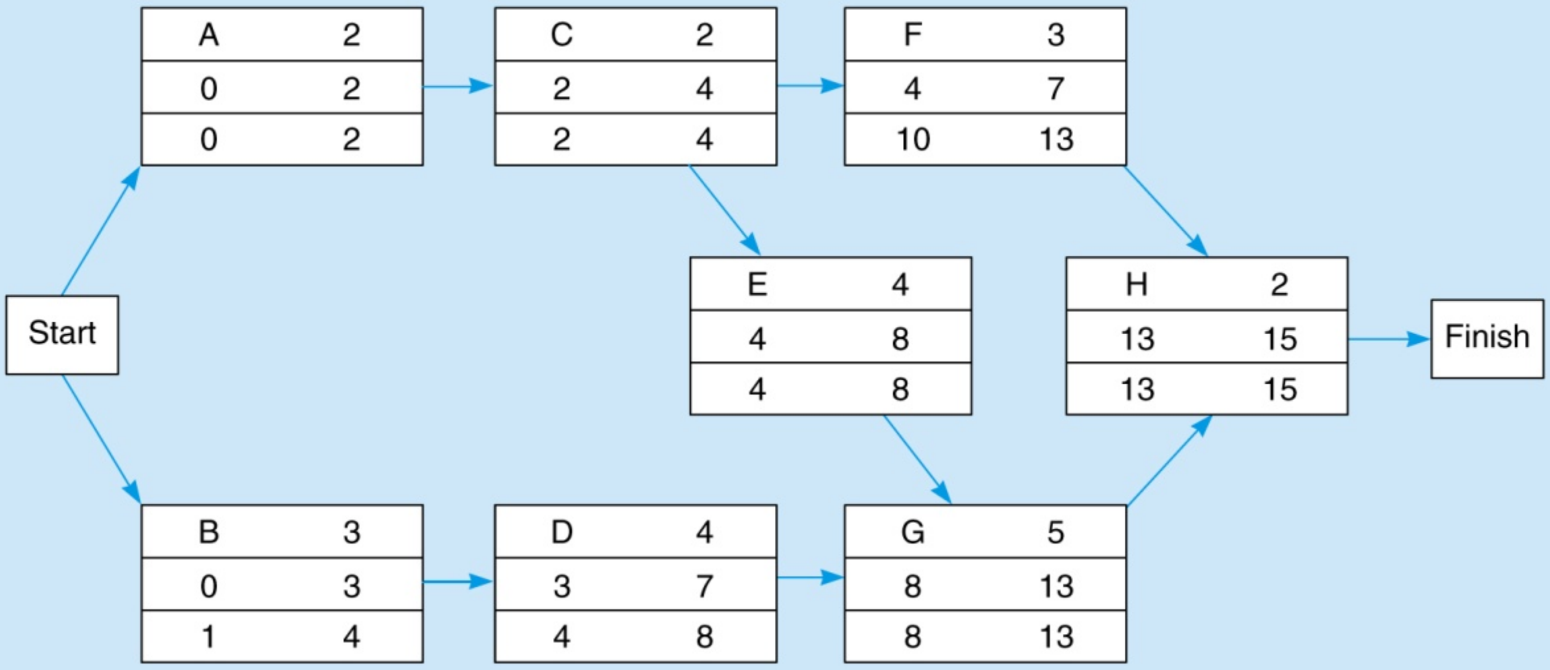


Figure 12.5

How to Find the Critical Path

- Once ES, LS, EF, and LF have been determined, it is a simple matter to find the amount of ***slack time*** that each activity has:

  Slack = LS – ES, or Slack = LF – EF

- From Table 12.3 we see activities *A*, *C*, *E*, *G*, and *H* have no slack time.
- These are called ***critical activities*** and they are said to be on the ***critical path.***
- The total project completion time is 15 weeks.
- Industrial managers call this a boundary timetable.

How to Find the Critical Path

General Foundry's Schedule and Slack Times

ACTIVITY	EARLIEST START, ES	EARLIEST FINISH, EF	LATEST START, LS	LATEST FINISH, LF	SLACK, LS – ES	ON CRITICAL PATH?
A	0	2	0	2	0	Yes
B	0	3	1	4	1	No
C	2	4	2	4	0	Yes
D	3	7	4	8	1	No
E	4	8	4	8	0	Yes
F	4	7	10	13	6	No
G	8	13	8	13	0	Yes
H	13	15	13	15	0	Yes

Table 12.3

How to Find the Critical Path

General Foundry's Critical Path

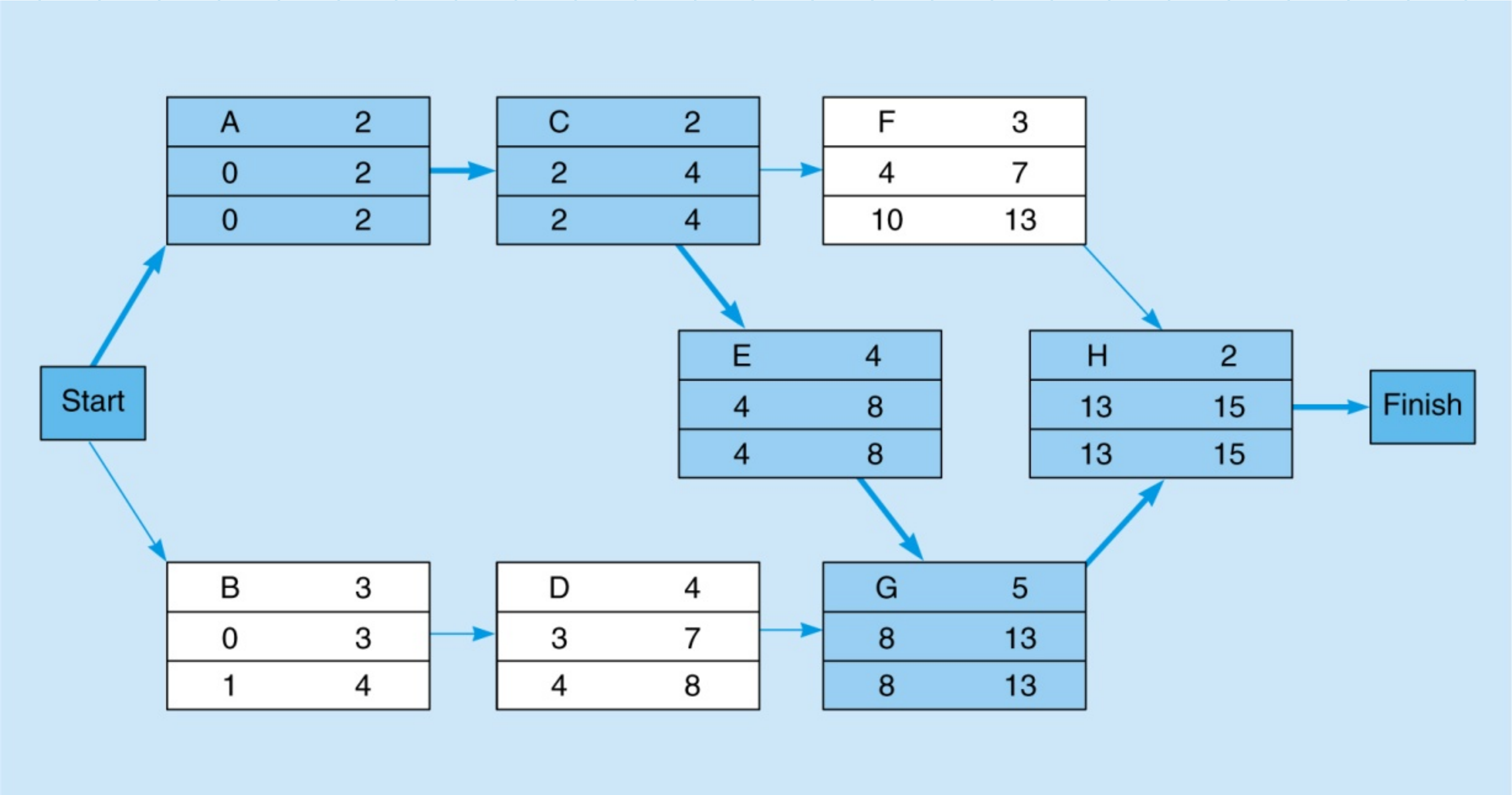


Figure 12.6

Probability of Project Completion

- The ***critical path analysis*** helped determine the expected project completion time of 15 weeks.
- But variation in activities on the critical path can affect overall project completion, and this is a major concern.
- If the project is not complete in 16 weeks, the foundry will have to close.
- PERT uses the variance of critical path activities to help determine the variance of the overall project.

$$\text{Project variance} = \sum \text{variances of activities on the critical path}$$

Probability of Project Completion

- From Table 12.2 we know that

ACTIVITY	VARIANCE
A	4/36
C	4/36
E	36/36
G	64/36
H	4/36

- Hence, the project variance is

Project variance $= {}^{4}/_{36} + {}^{4}/_{36} + {}^{36}/_{36} + {}^{64}/_{36} + {}^{4}/_{36} = {}^{112}/_{36} = 3.111$

Probability of Project Completion

- We know the standard deviation is just the square root of the variance, so:

$$\text{Project standard deviation} = \sigma_T = \sqrt{\text{Project variance}}$$

$$= \sqrt{3.11} = 1.76 \text{ weeks}$$

- We assume activity times are independent and that total project completion time is normally distributed.

Probability Distribution for Project Completion Times

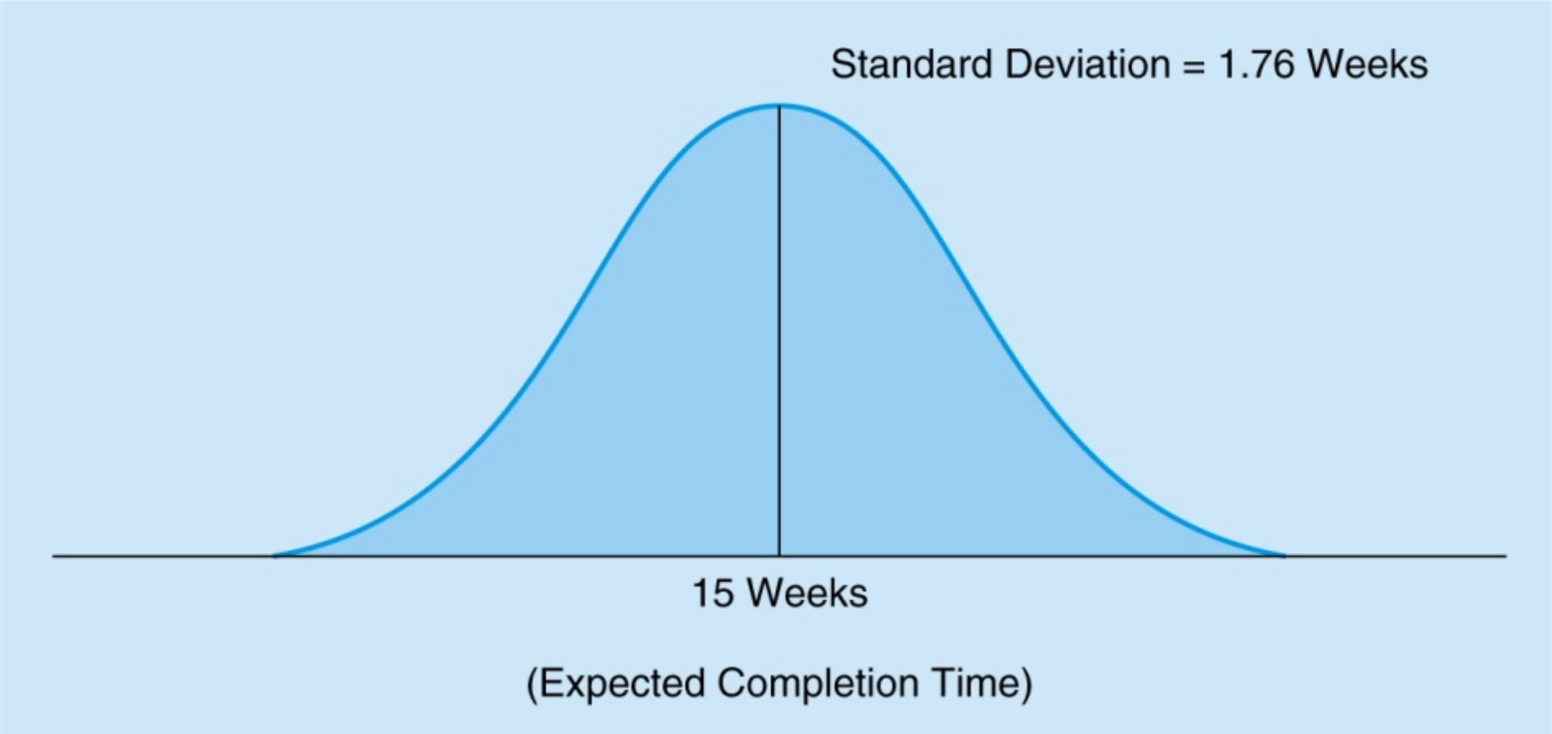


Figure 12.7

Probability of Project Completion

The standard normal equation can be applied as follows:

$$Z = \frac{\text{Due date} - \text{Expected date of completion}}{\sigma_T}$$

$$= \frac{16 \text{ weeks} - 15 \text{ weeks}}{1.76 \text{ weeks}} = 0.57$$

- From Appendix A we find the probability of 0.71566 associated with this Z value.
- That means the probability this project can be completed in 16 weeks or less is 0.716.

Probability of General Foundry Meeting the 16-week Deadline

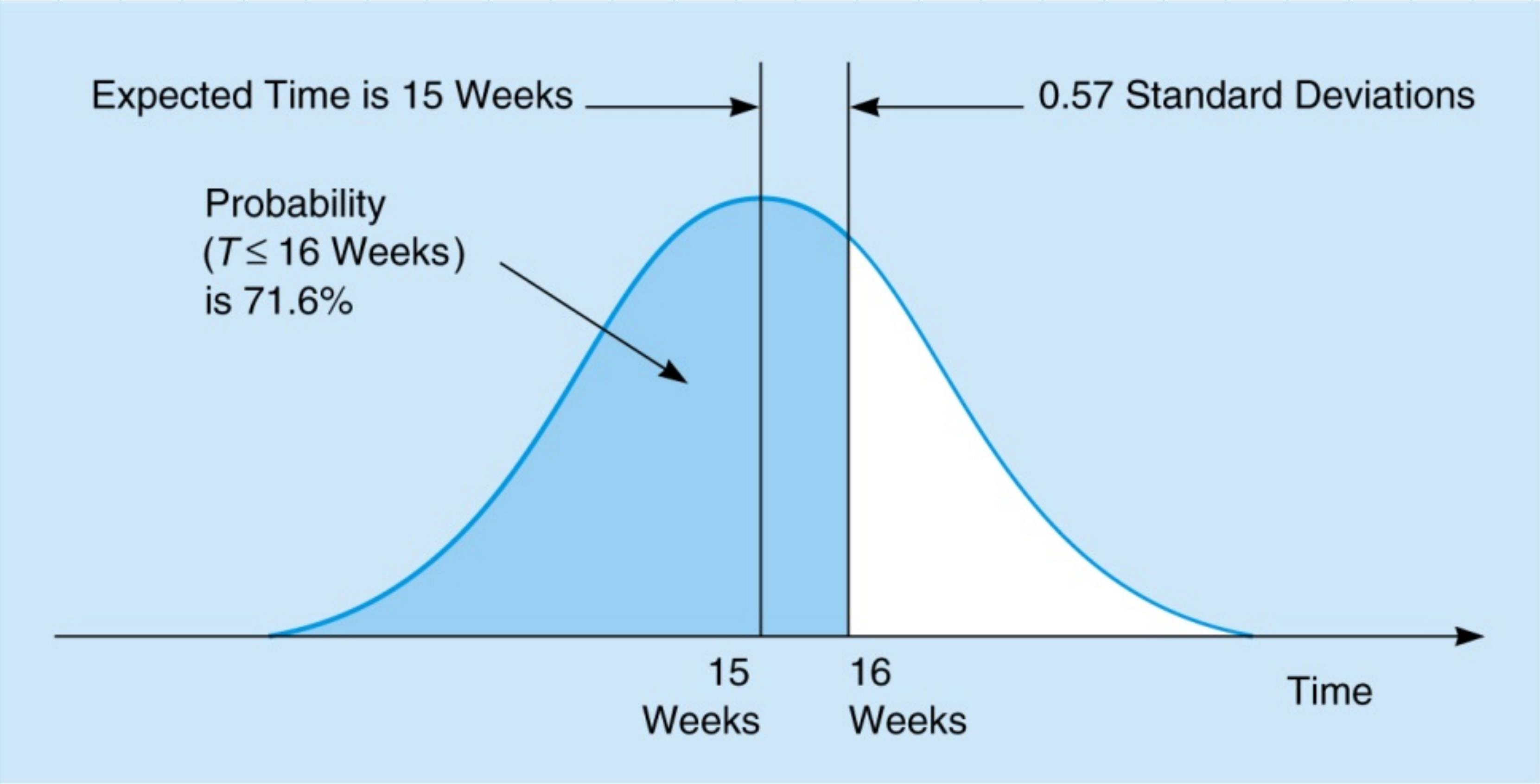


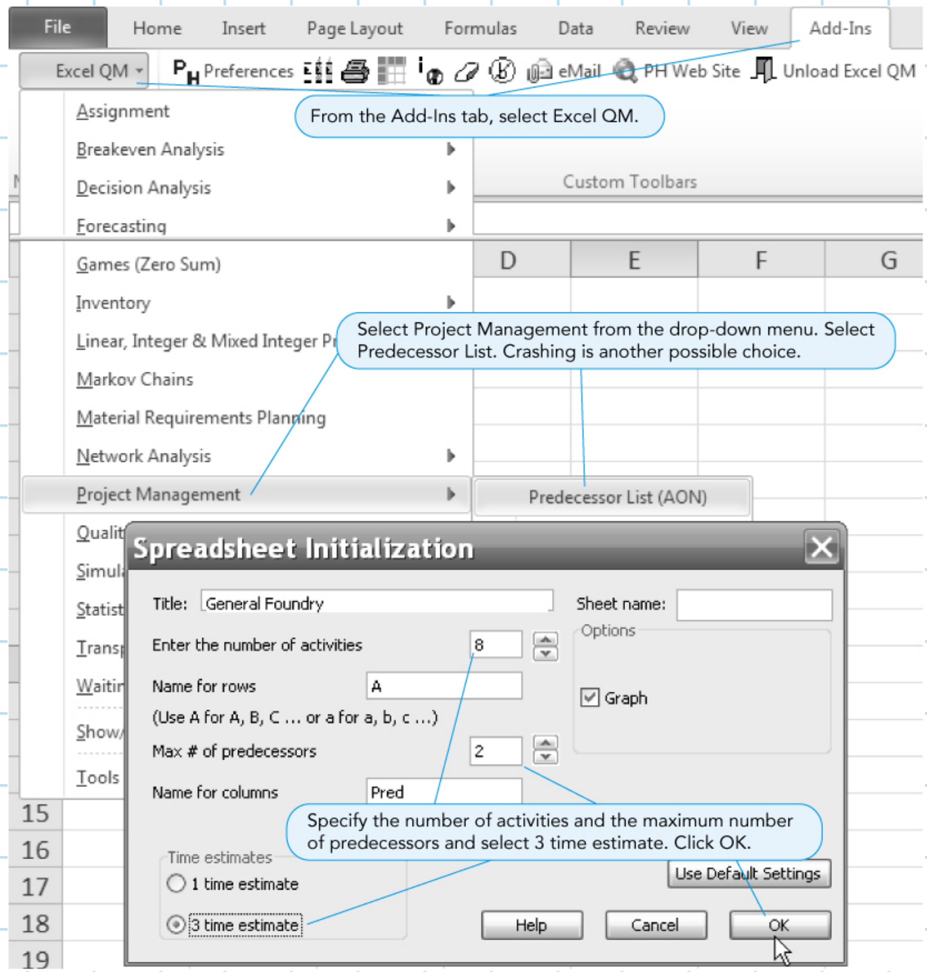
Figure 12.8

What PERT Was Able to Provide

- PERT has been able to provide the project manager with several valuable pieces of information.
- The project's expected completion date is 15 weeks.
- There is a 71.6% chance that the equipment will be in place within the 16-week deadline.
- Five activities (*A*, *C*, *E*, *G*, *H*) are on the critical path.
- Three activities (*B*, *D*, *F*) are not critical but have some slack time built in.
- A detailed schedule of activity starting and ending dates has been made available.

Using Excel QM in the General Foundry Example

Excel QM Initialization Screen for General Foundry Example with Three Time Estimates



Program 12.1A

Using Excel QM in the General Foundry Example

Excel QM Input Screen and Solution for General Foundry Example with Three Time Estimates

General Foundry

Input the three time estimates for each activity.

Enter the times in the appropriate column(s). Enter the prec

Mean times and standard deviations are automatically calculated.

Data

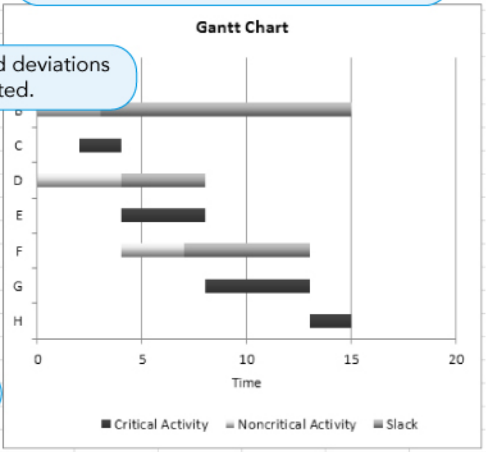
Activity	Optimistic	Likely	Pessimistic		Mean	Std dev	Variance
A	1	2	3		2	0.333333	0.111111
B	2	3	4		3	0.333333	0.111111
C	1	2	3		2	0.333333	0.111111
D	2	4	6		4	0.666667	0.444444
E	1	4	7		4	1	1
F	1	2	9		3	1.333333	1.777778
G	3	4	11		5	1.333333	1.777778
H	1	2	3		2	0.333333	0.111111

Precedences Immediate Predecessors (1 per column)

Enter the immediate predecessors.

Activity	Time	Pred 1	Pred 2
A	2		
B	3		
C	2	A	
D	4	B	
E	4	C	
F	3	C	
G	5	D	E
H	2	F	G

The Gantt chart shows the critical path and the slack for the noncritical activities.



A table is displayed, with all the earliest, latest, and slack times.

Results

Activity	Early Start	Early Finish	Late Start	Late Finish	Slack		Variance
A	0	2	0	2	0		0.1111111
B	0	3	12	15	12		
C	2	4	2	4	0		0.1111111
D	0	4	4	8	4		
E	4	8	4	8	0		1
F	4	7	10	13	6		
G	8	13	8	13	0		1.7777778
H	13	15	13	15	0		0.1111111
	Project	15				Project	3.1111111

Program 12.1B

Sensitivity Analysis and Project Management

- The time required to complete an activity can vary from the projected or expected time.
- If the activity is on the critical path, the completion time of the project will change.
- This will also have an impact on ES, EF, LS, and LF times for other activities.
- The exact impact depends on the relationship between the various activities.
- A *predecessor activity* is one that must be accomplished before the given activity can be started.
- A *successor activity* is one that can be started only after the given activity is finished.

Sensitivity Analysis and Project Management

Impact of an Increase (Decrease) in an Activity Time for a Critical Path Activity

ACTIVITY TIME	SUCCESSOR ACTIVITY	PARALLEL ACTIVITY	PREDECESSOR ACTIVITY
Earliest start	Increase (decrease)	No change	No change
Earliest finish	Increase (decrease)	No change	No change
Latest start	Increase (decrease)	Increase (decrease)	No change
Latest finish	Increase (decrease)	Increase (decrease)	No change
Slack	No change	Increase (decrease)	No change

Table 12.4

PERT/COST

- Although PERT is an excellent method of monitoring and controlling project length, it does not consider the very important factor of project cost.
- ***PERT/Cost*** is a modification of PERT that allows a manager to plan, schedule, monitor, and control cost as well as time.
- Using PERT/Cost to plan, schedule, monitor, and control project cost helps accomplish the sixth and final step of PERT.

Planning and Scheduling Project Costs: Budgeting Process

- **The overall approach in the budgeting process of a project is to determine how much is to be spent every week or month.**
- **This can be accomplished in four basic budgeting steps:**

Four Steps of the Budgeting Process

1. Identify all costs associated with each of the activities then add these costs together to get one estimated cost or budget for each activity.
2. In large projects, activities can be combined into larger work packages. A ***work package*** is simply a logical collection of activities.
3. Convert the budgeted cost per activity into a cost per time period by assuming that the cost of completing any activity is spent at a uniform rate over time.
4. Using the ES and LS times, find out how much money should be spent during each week or month to finish the project by the date desired.

Budgeting for General Foundry

- The Gantt chart in Figure 12.9 illustrates this process.
- The horizontal bars shown when each activity will be performed based on its ES-EF times.
- We determine how much will be spent on each activity during each week and fill these amounts into a chart in place of the bars.
- The following two tables show the activity costs and budgeted cost for the General Foundry project.

Budgeting for General Foundry

Gantt chart General Foundry project

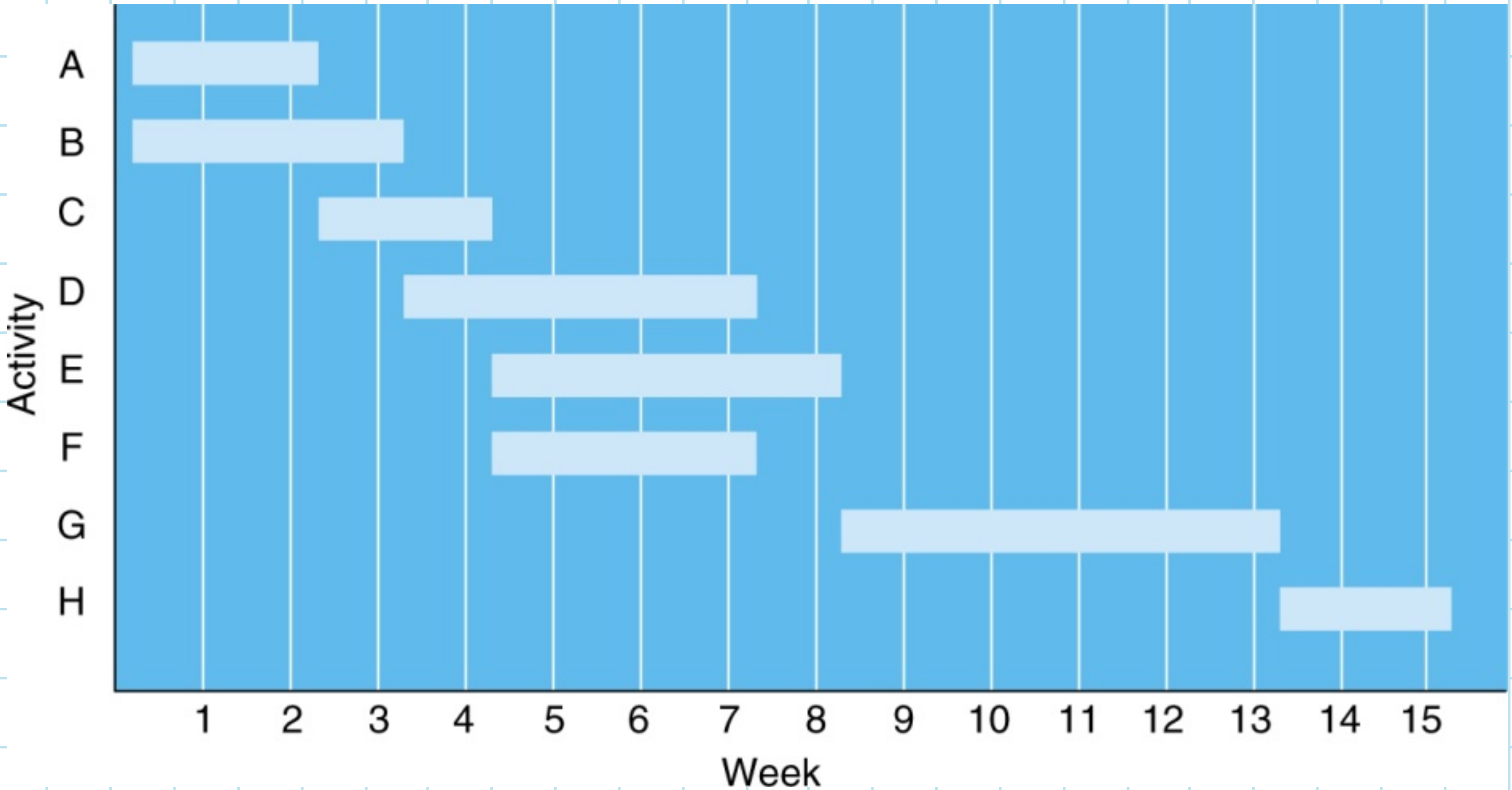


Figure 12.9

Budgeting for General Foundry

Activity costs for General Foundry, Inc.

ACTIVITY	EARLIEST START, ES	LATEST START, LS	EXPECTED TIME, t	TOTAL BUDGETED COST ($)	BUDGETED COST PER WEEK ($)
A	0	0	2	22,000	11,000
B	0	1	3	30,000	10,000
C	2	2	2	26,000	13,000
D	3	4	4	48,000	12,000
E	4	4	4	56,000	14,000
F	4	10	3	30,000	10,000
G	8	8	5	80,000	16,000
H	13	13	2	16,000	8,000
			Total	308,000	

Table 12.5

Budgeted Cost (Thousands of Dollars) for General Foundry, Inc., Using Earliest Start Times

	WEEK															
ACTIVITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL
A	11	11														22
B	10	10	10													30
C			13	13												26
D				12	12	12	12									48
E					14	14	14	14								56
F					10	10	10									30
G									16	16	16	16	16			80
H														8	8	16
																308
Total per week	21	21	23	25	36	36	36	14	16	16	16	16	16	8	8	
Total to date	21	42	65	90	126	162	198	212	228	244	260	276	292	300	308	

Table 12.6

Budgeting for General Foundry

- It is also possible to prepare a budget based on the latest starting time.
- This budget will delay the expenditure of funds until the last possible moment.
- The following table shows the latest start budget for the General Foundry project.
- The two tables form a budget range.
- Any budget can be chosen between these two values depending on when the company wants to actually spend the money.
- The budget ranges are plotted in Figure 12.10

Budgeted Cost (Thousands of Dollars) for General Foundry, Inc., Using Latest Start Times

	WEEK															
ACTIVITY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	TOTAL
A	11	11														22
B		10	10	10												30
C			13	13												26
D					12	12	12	12								48
E					14	14	14	14								56
F											10	10	10			30
G									16	16	16	16	16			80
H														8	8	16
																308
Total per week	11	21	23	23	26	26	26	26	16	16	26	26	26	8	8	
Total to date	11	32	55	78	104	130	156	182	198	214	240	266	292	300	308	

Table 12.7

Budget Ranges for General Foundry

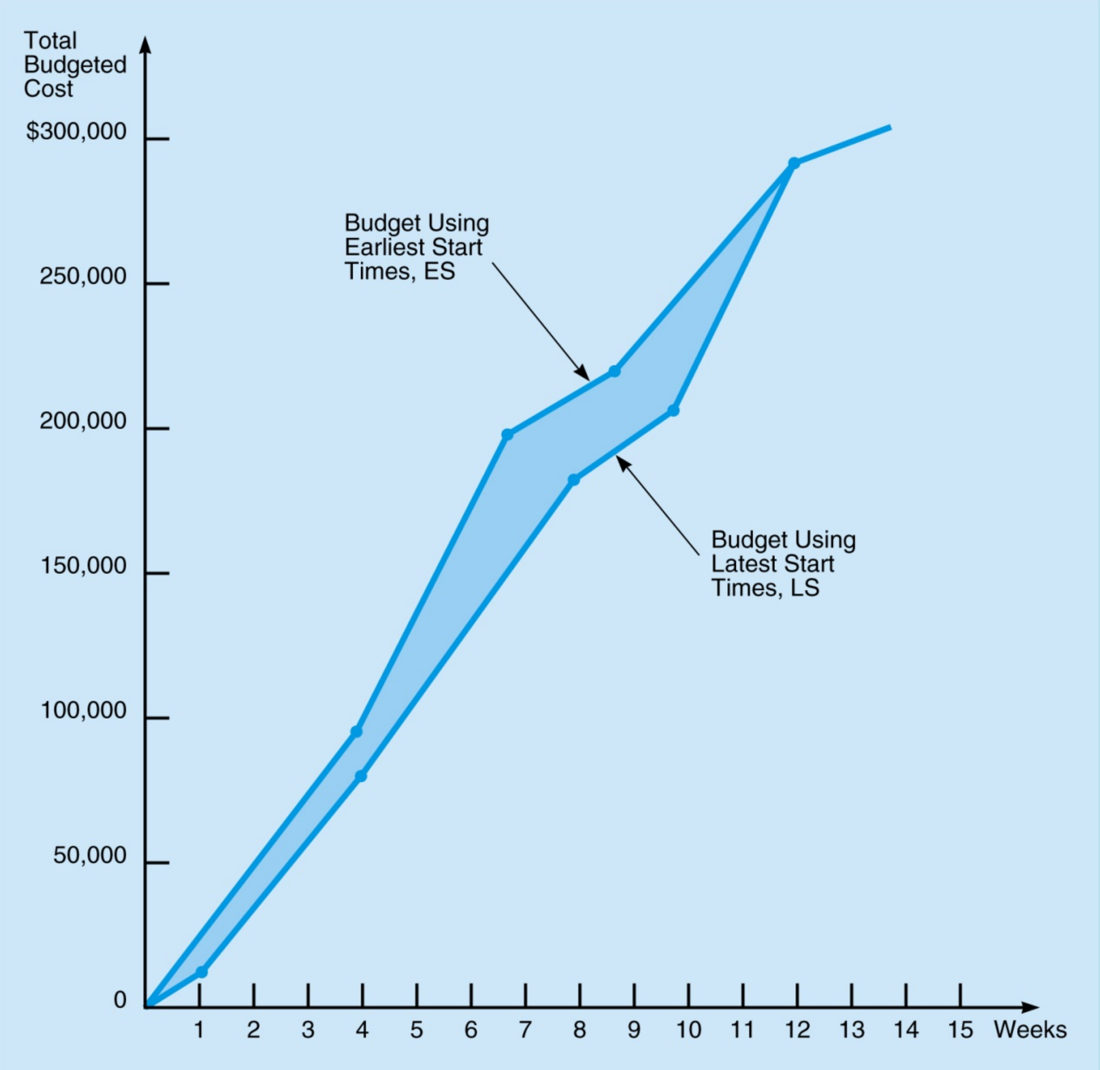


Figure 12.10

Monitoring and Controlling Project Costs

- Costs are monitored and controlled to ensure the project is progressing on schedule and that cost overruns are kept to a minimum.
- The status of the entire project should be checked periodically.
- The following table shows the state of the project in the sixth week.
- It can be used the answer questions about the schedule and costs so far.

Monitoring and Controlling Budgeted Cost

ACTIVITY	TOTAL BUDGETED COST ($)	PERCENT OF COMPLETION	VALUE OF WORK COMPLETED ($)	ACTUAL COST ($)	ACTIVITY DIFFERENCE ($)
A	22,000	100	22,000	20,000	–2,000
B	30,000	100	30,000	36,000	6,000
C	26,000	100	26,000	26,000	0
D	48,000	10	4,800	6,000	1,200
E	56,000	20	11,200	20,000	8,800
F	30,000	20	6,000	4,000	–2,000
G	80,000	0	0	0	0
H	16,000	0	0	0	0
		Total	100,000	112,000	12,000

Table 12.8

Overrun

Monitoring and Controlling Project Costs

The value of work completed, or the cost to date for any activity, can be computed as follows:

Value of work completed = (Percentage of work complete) x (Total activity budget)

The activity difference is also of interest:

Activity difference = Actual cost – Value of work completed

A negative activity difference is a cost underrun and a positive activity difference is a cost overrun.

Project Crashing

- Projects will sometimes have deadlines that are impossible to meet using normal procedures.
- By using exceptional methods it may be possible to finish the project in less time than normally required at a greater cost.
- Reducing a project's completion time is called ***crashing.***

Project Crashing

- Crashing a project starts with using the ***normal time*** to create the critical path.
- The ***normal cost*** is the cost for completing the activity using normal procedures.
- If the project will not meet the required deadline, extraordinary measures must be taken.
  - The ***crash time*** is the shortest possible activity time and will require additional resources.
  - The ***crash cost*** is the price of completing the activity in the earlier-than-normal time.

Four Steps to Project Crashing

1. **Find the normal critical path and identify the critical activities.**
2. **Compute the crash cost per week (or other time period) for all activities in the network using the formula:**

$$\text{Crash cost/Time period} = \frac{\text{Crash cost} - \text{Normal cost}}{\text{Normal time} - \text{Crash time}}$$

Four Steps to Project Crashing

3. Select the activity on the critical path with the smallest crash cost per week and crash this activity to the maximum extent possible or to the point at which your desired deadline has been reached.
4. Check to be sure that the critical path you were crashing is still critical. If the critical path is still the longest path through the network, return to step 3. If not, find the new critical path and return to step 2.

General Foundry

- Suppose that General Foundry has been given 14 weeks instead of 16 weeks to install the new equipment.
- The critical path for the project is 15 weeks.
- What options does the firm have?
  - The normal and crash times and costs are shown in Table 12.9.
  - Crash costs are assumed to be linear and Figure 12.11 shows the crash cost for activity *B.*
- Crashing activities *B* and *A* will shorten the completion time to 14 but it creates a second critical path.
- Any further crashing must be done to both critical paths.

General Foundry

Normal and Crash Data for General Foundry, Inc.

ACTIVITY	TIME (WEEKS) NORMAL	TIME (WEEKS) CRASH	COST ($) NORMAL	COST ($) CRASH	CRASH COST PER WEEK ($)	CRITICAL PATH?
A	2	1	22,000	23,000	1,000	Yes
B	3	1	30,000	34,000	2,000	No
C	2	1	26,000	27,000	1,000	Yes
D	4	3	48,000	49,000	1,000	No
E	4	2	56,000	58,000	1,000	Yes
F	3	2	30,000	30,500	500	No
G	5	2	80,000	86,000	2,000	Yes
H	2	1	16,000	19,000	3,000	Yes

Table 12.9

General Foundry

Crash and Normal Times and Costs for Activity *B*

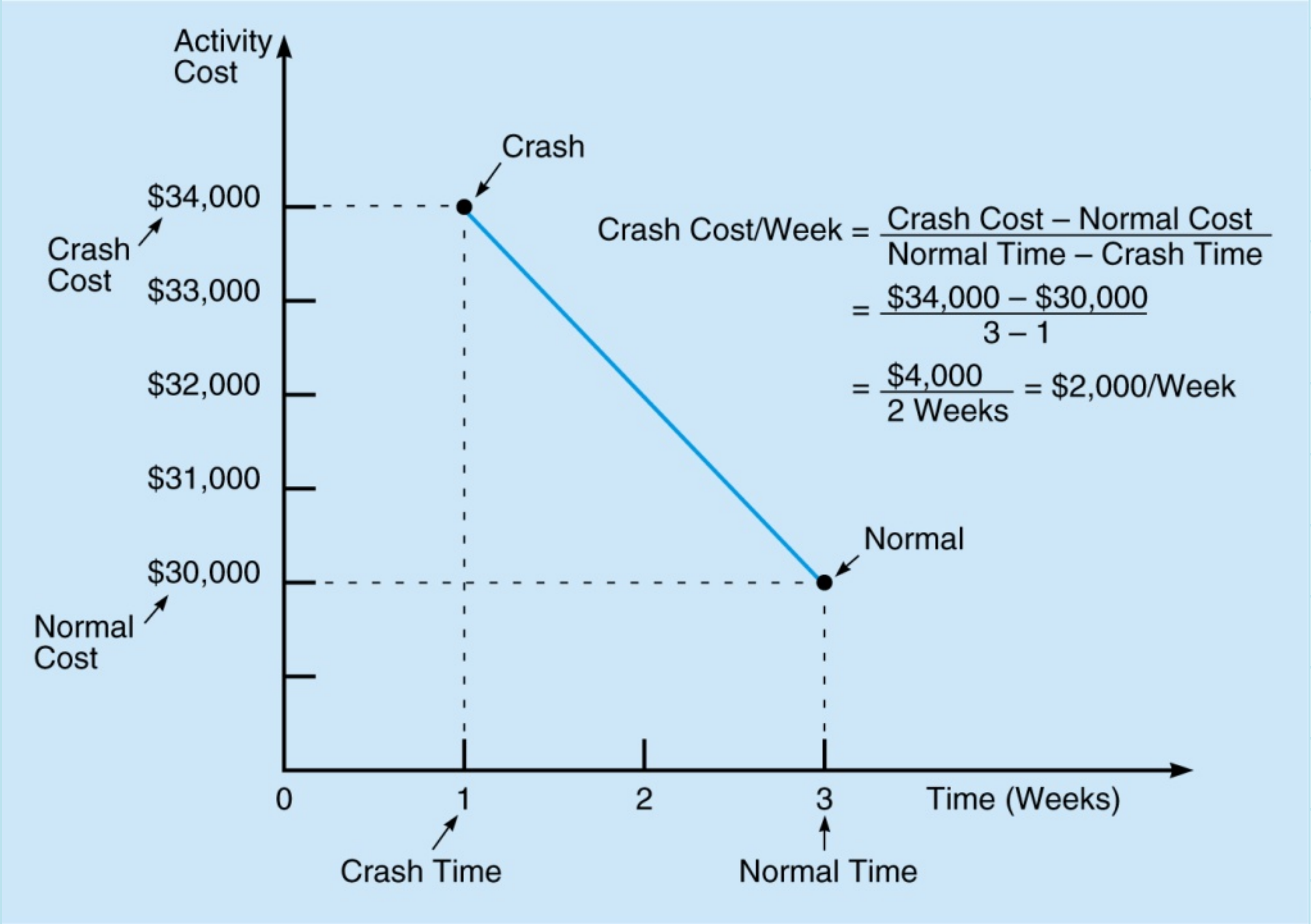


Figure 12.11

Project Crashing with Linear Programming

- Linear programming is another approach to finding the best project crashing schedule.
- The data needed are derived from the normal and crash data for General Foundry and the project network with activity times.

Project Crashing with Linear Programming

General Foundry's Network With Activity Times

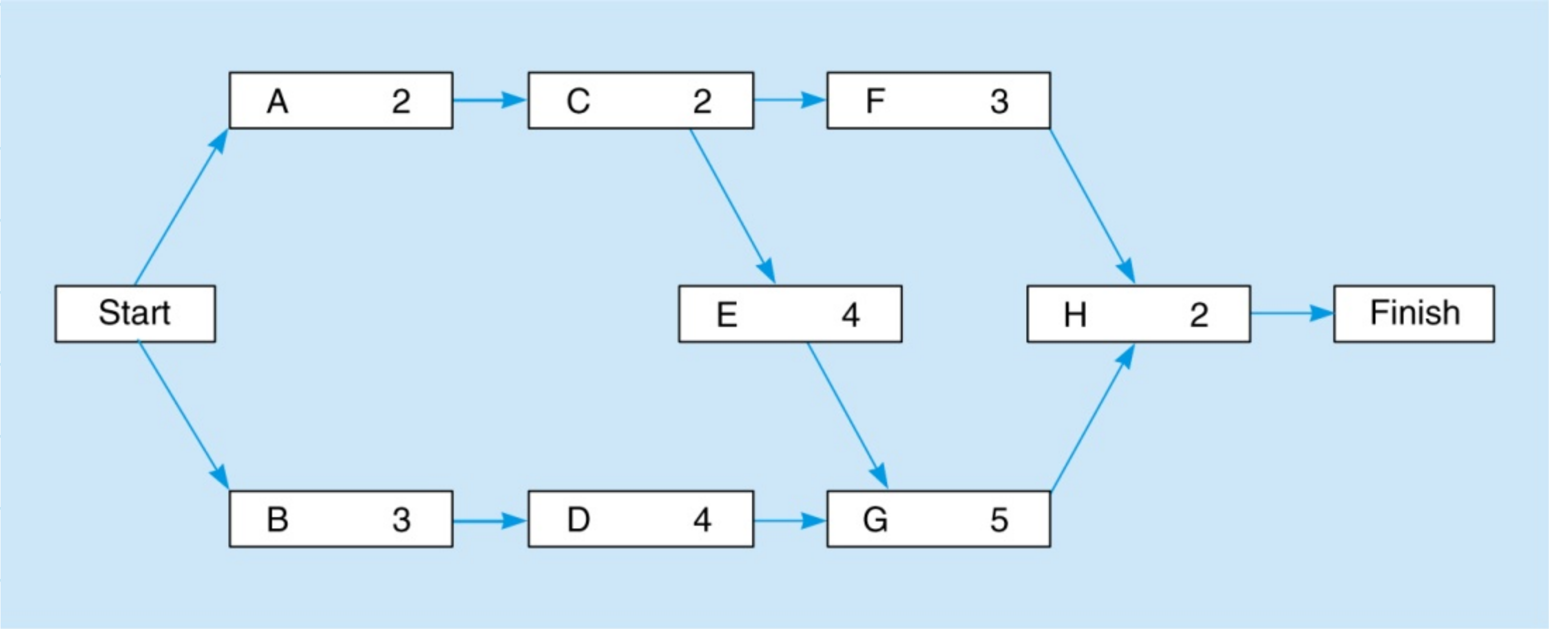


Figure 12.12

Project Crashing with Linear Programming

The decision variables for the problem are:

X_A = EF for activity *A*
X_B = EF for activity *B*
X_C = EF for activity *C*
X_D = EF for activity *D*
X_E = EF for activity *E*
X_F = EF for activity *F*
X_G = EF for activity *G*
X_H = EF for activity *H*
X_{start} = start time for project (usually 0)
X_{finish} = earliest finish time for the project

Project Crashing with Linear Programming

- Additional decision variables for the problem are:

  Y = the number of weeks that each activity is crashed.

  Y_A = the number of weeks activity *A* is crashed and so forth up to Y_H.

- The objective function is

  Minimize crash cost = $1{,}000Y_A + 2{,}000Y_B + 1{,}000Y_C + 1{,}000Y_D + 1{,}000Y_E + 500Y_F + 2{,}000Y_G + 3{,}000Y_H$

Project Crashing with Linear Programming

- Crash time constraints ensure activities are not crashed more than is allowed.

$$Y_A \leq 1$$
$$Y_B \leq 2$$
$$Y_C \leq 1$$
$$Y_D \leq 1$$
$$Y_E \leq 2$$
$$Y_F \leq 1$$
$$Y_G \leq 3$$
$$Y_H \leq 1$$

- This completion constraint specifies that the last event must take place before the project deadline:

$$X_{\text{finish}} \leq 12$$

- This constraint indicates the project is finished when activity *H* is finished:

$$X_{\text{finish}} \geq X_H$$

Project Crashing with Linear Programming

Constraints describing the network have the form:

EF time ≥ EF time for predecessor + Activity time

$EF \geq EF_{predecessor} + (t - Y)$, or

$X \geq X_{predecessor} + (t - Y)$

For activity *A*,	$X_A \geq X_{start} + (2 - Y_A)$	or	$X_A - X_{start} + Y_A \geq 2$
For activity *B*,	$X_B \geq X_{start} + (3 - Y_B)$	or	$X_B - X_{start} + Y_B \geq 3$
For activity *C*,	$X_C \geq X_A + (2 - Y_C)$	or	$X_C - X_A + Y_C \geq 2$
For activity *D*,	$X_D \geq X_B + (4 - Y_D)$	or	$X_D - X_B + Y_D \geq 4$
For activity *E*,	$X_E \geq X_C + (4 - Y_E)$	or	$X_E - X_C + Y_E \geq 4$
For activity *F*,	$X_F \geq X_C + (3 - Y_F)$	or	$X_F - X_C + Y_F \geq 3$
For activity *G*,	$X_G \geq X_D + (5 - Y_G)$	or	$X_G - X_D + Y_G \geq 5$
For activity *G*,	$X_G \geq X_E + (5 - Y_G)$	or	$X_G - X_E + Y_G \geq 5$
For activity *H*,	$X_H \geq X_F + (2 - Y_H)$	or	$X_H - X_F + Y_H \geq 2$
For activity *H*,	$X_H \geq X_G + (2 - Y_H)$	or	$X_H - X_G + Y_H \geq 2$

Solution to Crashing Problem Using Solver in Excel

Activity A is crashed 1 week, and activity G is crashed 2 weeks. There are other optimal solutions to this problem.

T4 = =SUMPRODUCT($B$3:$S$3,

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1	Crashing General Foundry Problem																						
2		YA	YB	YC	YD	YE	YF	YG	YH	XST	XA	XB	XC	XD	XE	XF	XG	XH	XFIN				
3	Values	1	0	0	0	0	0	2	0	0	1	3	3	7	7	10	10	12	12	Totals			
4	Minimize cost	1000	2000	1000	1000	1000	500	2000	3000											5000			
5	A crash max.	1																		1	<	1	
6	B crash max.		1																	0	<	2	
7	C crash max.			1																0	<	1	
8	D crash max.				1															0	<	1	
9	E crash max.					1														0	<	2	
10	F crash max.						1													0	<	1	
11	G crash max.							1												2	<	3	
12	H crash max.								1											0	<	1	
13	Due date																		1	12	<	12	
14	Start									1										0	=	0	
15	A constraint	1								-1	1									2	>	2	
16	B constraint		1							-1		1								3	>	3	
17	C constraint			1							-1		1							2	>	2	
18	D constraint				1							-1		1						4	>	4	
19	E constraint					1							-1		1					4	>	4	
20	F constraint						1						-1			1				7	>	3	
21	G constaint 1							1						-1			1			5	>	5	
22	G constraint 2							1							-1		1			5	>	5	
23	H constraint 1								1							-1		1		2	>	2	
24	H constraint 2								1								-1	1		2	>	2	
25	Finish constraint																	-1	1	0	>	0	

The total cost of crashing is $5,000.

The formula in cell T4 is copied down column T (from T5 to T25).

Program 12.2

Other Topics in Project Management

- Subprojects
  - For extremely large projects, an activity may be made of several smaller sub-activities which can be viewed as a smaller project or subproject of the original .
- Milestones
  - Major events in a project are often referred to as ***milestones*** and may be reflected in ***Gantt charts*** and PERT charts to highlight the importance of reaching these events.

Other Topics in Project Management

- Resource Leveling
  - *Resource leveling* adjusts the activity start away from the early start so that resource utilization is more evenly distributed over time.
- Software
  - There are many project management software packages on the market for both personal computers and larger mainframe machines.
  - Most of these create PERT charts and Gantt charts and can be used to develop budget schedules, adjust future start times, and level resource utilization.

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