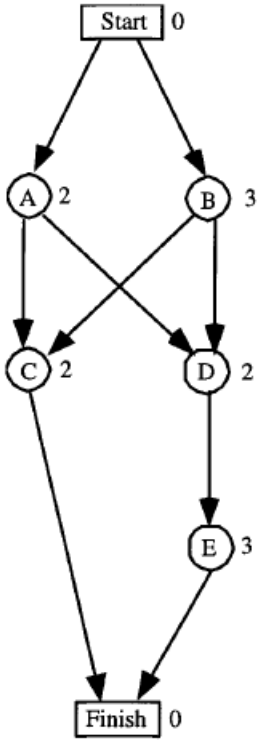
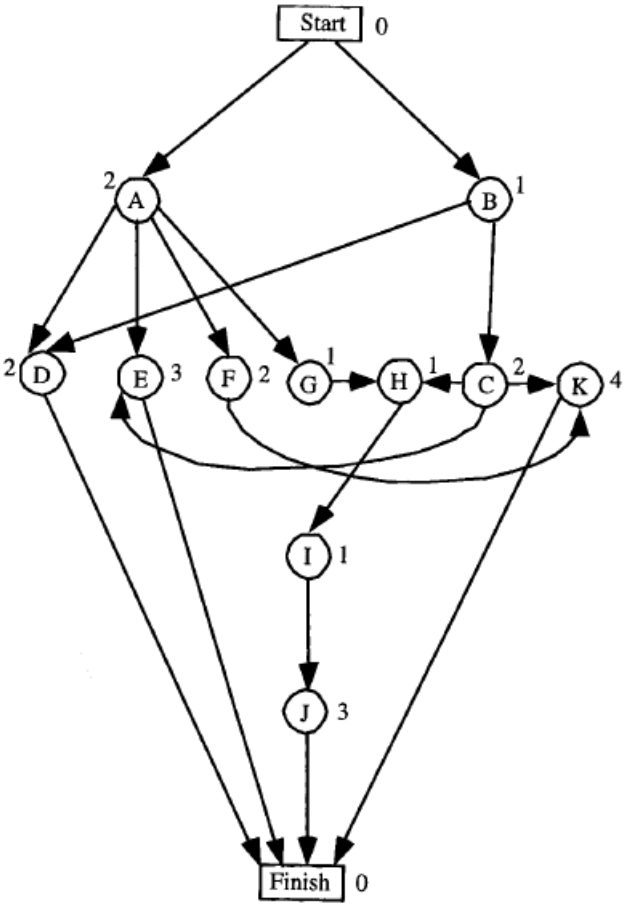
CHAPTER 22: PROJECT MANAGEMENT WITH PERT/CPM

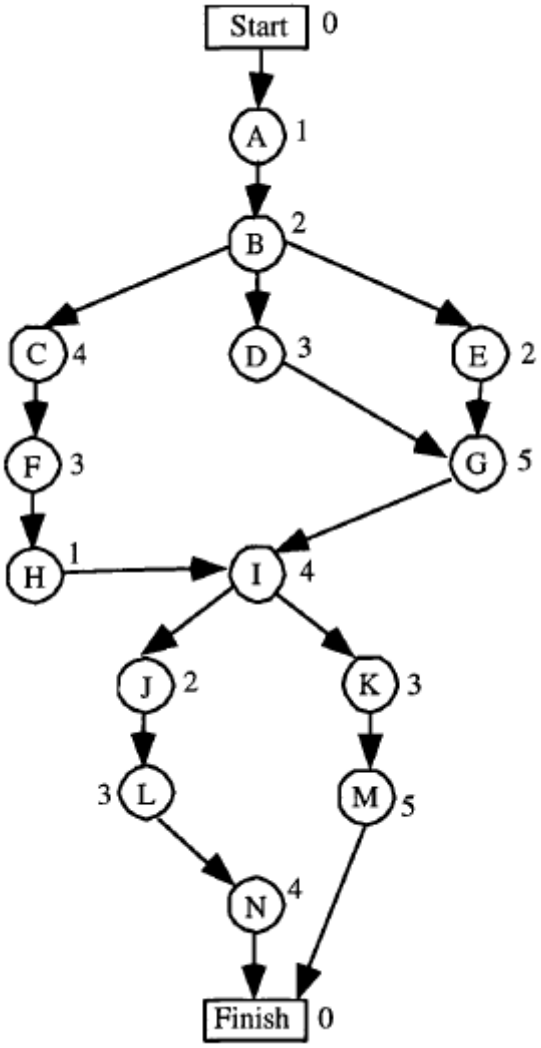
22.2-1.



22.2-2.

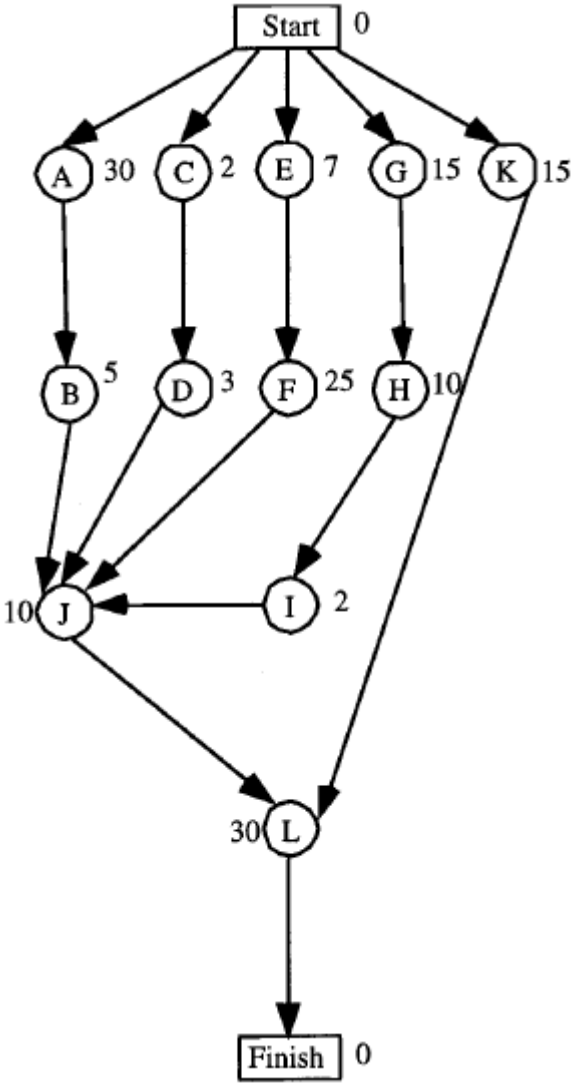


22.2-3.



22.3-1.

(a)



(b)

Start $\rightarrow A \rightarrow B \rightarrow J \rightarrow L \rightarrow$ Finish	Length $= 75$ minutes
Start $\rightarrow C \rightarrow D \rightarrow J \rightarrow L \rightarrow$ Finish	Length $= 45$ minutes
Start $\rightarrow E \rightarrow F \rightarrow J \rightarrow L \rightarrow$ Finish	Length $= 72$ minutes
Start $\rightarrow G \rightarrow H \rightarrow I \rightarrow J \rightarrow L \rightarrow$ Finish	Length $= 67$ minutes
Start $\rightarrow K \rightarrow L \rightarrow$ Finish	Length $= 45$ minutes

Hence, Start $\rightarrow A \rightarrow B \rightarrow J \rightarrow L \rightarrow$ Finish is the critical path.

(c) - (d) - (e)

Activity	ES	EF	LS	LF	Slack	Critical Path
Start	0	0	0	0	0	Yes
A	0	30	0	30	0	Yes
B	30	35	30	35	0	Yes
C	0	2	30	32	30	No
D	2	5	32	35	30	No
E	0	7	3	10	3	No
F	7	32	10	35	3	No
G	0	15	8	23	8	No
H	15	25	23	33	8	No
I	25	27	33	35	8	No
J	35	45	35	45	0	Yes
K	0	15	30	45	30	No
L	45	75	45	75	0	Yes
Finish	75	75	75	75	0	Yes

Critical Path: Start $\rightarrow A \rightarrow B \rightarrow J \rightarrow L \rightarrow$ Finish

(f) Dinner will be delayed three minutes because of the phone call. If the food processor is used, dinner will not be delayed, since there was a slack of three minutes, five minutes of cutting time is saved and the call used only six minutes of these eight minutes.

22.3-2.

(a)
Start $\rightarrow A \rightarrow C \rightarrow$ Finish — Length $= 4$ weeks
Start $\rightarrow A \rightarrow D \rightarrow E \rightarrow$ Finish — Length $= 7$ weeks
Start $\rightarrow B \rightarrow C \rightarrow$ Finish — Length $= 5$ weeks
Start $\rightarrow B \rightarrow D \rightarrow E \rightarrow$ Finish — Length $= 8$ weeks

Hence, Start $\rightarrow B \rightarrow D \rightarrow E \rightarrow$ Finish is the critical path.

(b)

Activity	ES	EF	LS	LF	Slack	Critical Path
Start	0	0	0	0	0	Yes
A	0	2	1	3	1	No
B	0	3	0	3	0	Yes
C	3	5	6	8	3	No
D	3	5	3	5	0	Yes
E	5	8	5	8	0	Yes
Finish	8	8	8	8	0	Yes

Critical Path: Start $\rightarrow B \rightarrow D \rightarrow E \rightarrow$ Finish

(c) No, this will not shorten the length of the project because the activity is not on the critical path.

22.3-3.

(a)

Start $\rightarrow A \rightarrow D \rightarrow$ Finish	Length $= 4$ weeks
Start $\rightarrow A \rightarrow E \rightarrow$ Finish	Length $= 5$ weeks
Start $\rightarrow A \rightarrow F \rightarrow K \rightarrow$ Finish	Length $= 8$ weeks
Start $\rightarrow A \rightarrow G \rightarrow H \rightarrow I \rightarrow J \rightarrow$ Finish	Length $= 8$ weeks
Start $\rightarrow B \rightarrow D \rightarrow$ Finish	Length $= 3$ weeks
Start $\rightarrow B \rightarrow C \rightarrow E \rightarrow$ Finish	Length $= 6$ weeks
Start $\rightarrow B \rightarrow C \rightarrow H \rightarrow I \rightarrow J \rightarrow$ Finish	Length $= 8$ weeks
Start $\rightarrow B \rightarrow C \rightarrow K \rightarrow$ Finish	Length $= 7$ weeks

Critical Paths: Start $\rightarrow A \rightarrow F \rightarrow K \rightarrow$ Finish
Start $\rightarrow A \rightarrow G \rightarrow H \rightarrow I \rightarrow J \rightarrow$ Finish
Start $\rightarrow B \rightarrow C \rightarrow H \rightarrow I \rightarrow J \rightarrow$ Finish

(b)

Activity	ES	EF	LS	LF	Slack	Critical Path
Start	0	0	0	0	0	Yes
A	0	2	0	2	0	Yes
B	0	1	0	1	0	Yes
C	1	3	1	3	0	Yes
D	2	4	6	8	4	No
E	3	6	5	8	2	No
F	2	4	2	4	0	Yes
G	2	3	2	3	0	Yes
H	3	4	3	4	0	Yes
I	4	5	4	5	0	Yes
J	5	8	5	8	0	Yes
K	4	8	4	8	0	Yes
Finish	8	8	8	8	0	Yes

Critical Paths: Start $\rightarrow A \rightarrow F \rightarrow K \rightarrow$ Finish
Start $\rightarrow A \rightarrow G \rightarrow H \rightarrow I \rightarrow J \rightarrow$ Finish
Start $\rightarrow B \rightarrow C \rightarrow H \rightarrow I \rightarrow J \rightarrow$ Finish

(c) No, this will not shorten the length of the project because A is not on all of the critical paths.

22.3-4.

(a)

Start $\rightarrow A \rightarrow D \rightarrow H \rightarrow M \rightarrow$ Finish	Length $= 19$ weeks
Start $\rightarrow B \rightarrow E \rightarrow J \rightarrow M \rightarrow$ Finish	Length $= 20$ weeks
Start $\rightarrow C \rightarrow F \rightarrow K \rightarrow N \rightarrow$ Finish	Length $= 16$ weeks
Start $\rightarrow A \rightarrow I \rightarrow M \rightarrow$ Finish	Length $= 17$ weeks
Start $\rightarrow C \rightarrow G \rightarrow L \rightarrow N \rightarrow$ Finish	Length $= 20$ weeks

Critical Paths: Start $\rightarrow B \rightarrow E \rightarrow J \rightarrow M \rightarrow$ Finish
Start $\rightarrow C \rightarrow G \rightarrow L \rightarrow N \rightarrow$ Finish

(b)

Activity	ES	EF	LS	LF	Slack	Critical Path
Start	0	0	0	0	0	Yes
A	0	6	1	7	1	No
B	0	3	0	3	0	Yes
C	0	4	0	4	0	Yes
D	6	10	7	11	1	No
E	3	10	3	10	0	Yes
F	4	8	8	12	4	No
G	4	10	4	10	0	Yes
H	10	13	11	14	1	No
I	6	11	9	14	3	No
J	10	14	10	14	0	Yes
K	8	11	12	15	4	No
L	10	15	10	15	0	Yes
M	14	20	14	20	0	Yes
N	15	20	15	20	0	Yes
Finish	20	20	20	20	0	Yes

Ken will be able to meet his deadline.

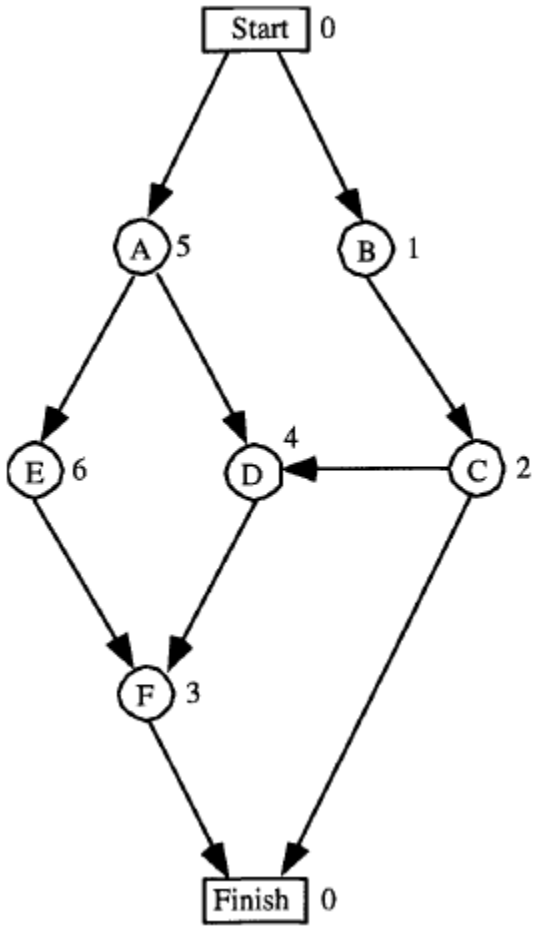
(c) Critical Paths: Start $\rightarrow B \rightarrow E \rightarrow J \rightarrow M \rightarrow$ Finish
Start $\rightarrow C \rightarrow G \rightarrow L \rightarrow N \rightarrow$ Finish

Focus attention on activities with no slack.

(d) If activity I takes two more weeks, there will be no delay because its slack is three. If activity H takes two extra weeks, then there will be a delay of one week because its slack is only one week. If activity J takes two more weeks, there will be a delay of two weeks, since it has no slack.

22.3-5.

(a)



(b)

Activity	ES	EF	LS	LF	Slack	Critical Path
Start	0	0	0	0	0	Yes
A	0	5	0	5	0	Yes
B	0	1	11	12	11	No
C	1	3	12	14	11	No
D	5	9	7	11	2	No
E	5	11	5	11	0	Yes
F	11	14	11	14	0	Yes
Finish	14	14	14	14	0	Yes

Critical Path: Start $\rightarrow A \rightarrow E \rightarrow F \rightarrow$ Finish

(c) 6 months

22.3-6.

Activity	ES	EF	LS	LF	Slack	Critical Path
Start	0	0	0	0	0	Yes
A	0	3	0	3	0	Yes
B	3	11	3	11	0	Yes
C	11	29	11	29	0	Yes
D	29	39	29	39	0	Yes
E	29	34	30	35	1	No
F	34	44	35	45	1	No
G	39	50	39	50	0	Yes
H	50	67	50	67	0	Yes
I	29	38	36	45	7	No
J	44	53	45	54	1	No
K	53	57	57	61	4	No
L	53	60	54	61	1	No
M	67	70	67	70	0	Yes
N	60	69	61	70	1	No
Finish	70	70	70	70	0	Yes

Critical Path: Start $\rightarrow A \rightarrow B \rightarrow C \rightarrow D \rightarrow G \rightarrow H \rightarrow M \rightarrow$ Finish
Total duration: 70 weeks

22.3-7.

Activity	ES	EF	LS	LF	Slack	Critical Path
Start	0	0	0	0	0	Yes
A	0	1	0	1	0	Yes
B	1	3	1	3	0	Yes
C	3	9	3	9	0	Yes
D	9	13	11	15	2	No
E	9	10	9	10	0	Yes
F	10	14	10	14	0	Yes
G	13	18	15	20	2	No
H	18	23	20	25	2	No
I	9	12	11	14	2	No
J	14	17	14	17	0	Yes
K	17	21	17	21	0	Yes
L	17	18	20	21	3	No
M	23	24	25	26	2	No
N	21	26	21	26	0	Yes
Finish	26	26	26	26	0	Yes

Critical Path: Start $\rightarrow A \rightarrow B \rightarrow C \rightarrow E \rightarrow F \rightarrow J \rightarrow K \rightarrow N \rightarrow$ Finish
Total duration: 26 weeks

22.3-8.

Activity	ES	EF	LS	LF	Slack	Critical Path
Start	0	0	0	0	0	Yes
A	0	1	0	1	0	Yes
B	1	3	1	3	0	Yes
C	3	10	3	10	0	Yes
D	10	14	13	17	3	No
E	10	13	10	13	0	Yes
F	13	16	13	16	0	Yes
G	14	18	17	21	3	No
H	18	24	21	27	3	No
I	10	15	11	16	1	No
J	16	22	16	22	0	Yes
K	22	25	22	25	0	Yes
L	22	25	22	25	0	Yes
M	24	25	27	28	3	No
N	25	28	25	28	0	Yes
Finish	28	28	28	28	0	Yes

Critical Path: Start $\rightarrow A \rightarrow B \rightarrow C \rightarrow E \rightarrow F \rightarrow J \rightarrow K \rightarrow N \rightarrow$ Finish
Start $\rightarrow A \rightarrow B \rightarrow C \rightarrow E \rightarrow F \rightarrow J \rightarrow L \rightarrow N \rightarrow$ Finish
Total duration: 28 weeks

22.4-1.

$$\mu = \frac{o+4m+p}{6} = \frac{30+4(36)+48}{6} = 37$$

$$\sigma^2 = \left(\frac{p-o}{6}\right)^2 = \left(\frac{48-30}{6}\right)^2 = 9$$

22.4-2.

(a) Start $\rightarrow A \rightarrow E \rightarrow I \rightarrow$ Finish — Length = 17 months
Start $\rightarrow A \rightarrow C \rightarrow F \rightarrow I \rightarrow$ Finish — Length = 17 months
Start $\rightarrow B \rightarrow D \rightarrow G \rightarrow J \rightarrow$ Finish — Length = 17 months
Start $\rightarrow B \rightarrow H \rightarrow J \rightarrow$ Finish — Length = 18 months

Critical Path: Start $\rightarrow B \rightarrow H \rightarrow J \rightarrow$ Finish

(b) $\frac{d-\mu_p}{\sqrt{\sigma_p}} = \frac{22-18}{\sqrt{31}} = 0.718 \Rightarrow \mathrm{P}\{T \leq 22\} \approx 0.77$

(c) Start $\rightarrow A \rightarrow E \rightarrow I \rightarrow$ Finish: $\frac{d-\mu_p}{\sqrt{\sigma_p}} = \frac{22-17}{\sqrt{25}} = 1 \Rightarrow \mathrm{P}\{T \leq 22\} \approx 0.84$

Start $\rightarrow A \rightarrow C \rightarrow F \rightarrow I \rightarrow$ Finish: $\frac{d-\mu_p}{\sqrt{\sigma_p}} = \frac{22-17}{\sqrt{27}} = 0.962 \Rightarrow \mathrm{P}\{T \leq 22\} \approx 0.84$

Start $\rightarrow B \rightarrow D \rightarrow G \rightarrow J \rightarrow$ Finish: $\frac{d-\mu_p}{\sqrt{\sigma_p}} = \frac{22-17}{\sqrt{28}} = 0.945 \Rightarrow \mathrm{P}\{T \leq 22\} \approx 0.84$

(d) There is approximately a 77% chance that the drug will be ready in 22 weeks.

22.4-3.

Start → B → H → J → Finish

Mean Critical Path	
μ =	18.417
σ^2 =	31.201
P(T<=d) =	0.7394
where	
d =	22

Start → A → E → I → Finish

Mean Critical Path	
μ =	18.417
σ^2 =	31.201
P(T<=d) =	0.7394
where	
d =	22

Start → A → C → F → I → Finish

Mean Critical Path	
μ =	17.583
σ^2 =	27.368
P(T<=d) =	0.8007
where	
d =	22

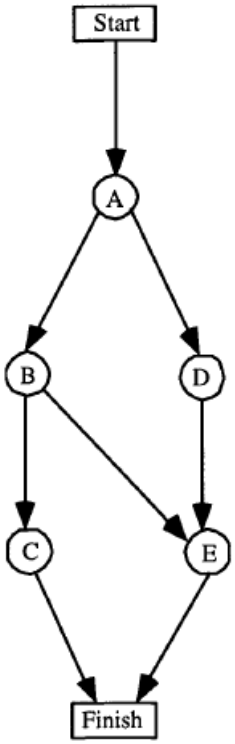
Start → B → D → G → J → Finish

Mean Critical Path	
μ =	17.833
σ^2 =	28.042
P(T<=d) =	0.7843
where	
d =	22

There is approximately a 73% chance that the drug will be ready in 22 weeks.

22.4-4.

(a)



(b)

Activity	μ	σ^2
A	4	0.111
B	2	0
C	4.83	0.25
D	3	0.444
E	3.17	0.25

(c) Start $\rightarrow A \rightarrow B \rightarrow C \rightarrow$ Finish Length $= 10.83$ weeks
Start $\rightarrow A \rightarrow B \rightarrow E \rightarrow$ Finish Length $= 9.17$ weeks
Start $\rightarrow A \rightarrow D \rightarrow E \rightarrow$ Finish Length $= 10.17$ weeks

Critical Path: Start $\rightarrow A \rightarrow B \rightarrow C \rightarrow$ Finish

(d) $\frac{d-\mu_p}{\sqrt{\sigma_p}} = \frac{11-10.83}{\sqrt{0.361}} = 0.028 \Rightarrow \text{P}\{T \leq 11\} = 0.6$

(e) Make the bid, since there is approximately a 60% chance that the project will be completed in 11 weeks or less.

22.4-5.

(a)

Activity	μ	σ^2
A	12	0
B	23	16
C	15	1
D	27	9
E	18	4
F	6	4

(b) Start $\rightarrow A \rightarrow C \rightarrow E \rightarrow F \rightarrow$ Finish Length $= 51$ days
Start $\rightarrow B \rightarrow D \rightarrow$ Finish Length $= 50$ days

Critical Path: Start $\rightarrow A \rightarrow C \rightarrow E \rightarrow F \rightarrow$ Finish

(c) $\frac{d-\mu_p}{\sqrt{\sigma_p}} = \frac{57-51}{\sqrt{9}} = 2 \Rightarrow \text{P}\{T \leq 57\} = 0.9772$ (Normal Distribution table)

(d) $\frac{d-\mu_p}{\sqrt{\sigma_p}} = \frac{57-50}{\sqrt{25}} = 1.4 \Rightarrow \text{P}\{T \leq 57\} = 0.9192$ (Normal Distribution table)

(e) $(0.9772)(0.9192) = 0.8982$, so the procedure used in (c) overestimates the probability of completing the project within 57 days.

22.4-6.

(a)

Activity	μ	σ^2
A	32	1.78
B	27.7	2.78
C	36	11.1
D	16	0.444
E	32	0
F	53.7	32.1
G	16.7	4
H	20.3	2.78
I	34	7.11
J	17.7	9

(b)
Start $\rightarrow A \rightarrow C \rightarrow J \rightarrow$ Finish — Length $= 85.7$ weeks
Start $\rightarrow B \rightarrow F \rightarrow J \rightarrow$ Finish — Length $= 99.1$ weeks
Start $\rightarrow B \rightarrow E \rightarrow H \rightarrow$ Finish — Length $= 80$ weeks
Start $\rightarrow B \rightarrow E \rightarrow I \rightarrow$ Finish — Length $= 93.7$ weeks
Start $\rightarrow B \rightarrow D \rightarrow G \rightarrow H \rightarrow$ Finish — Length $= 80.7$ weeks
Start $\rightarrow B \rightarrow D \rightarrow G \rightarrow I \rightarrow$ Finish — Length $= 94.4$ weeks

Critical Path: Start $\rightarrow B \rightarrow F \rightarrow J \rightarrow$ Finish

(c) $\frac{d-\mu_p}{\sqrt{\sigma_p}} = \frac{100-99.1}{\sqrt{43.89}} = 0.136 \Rightarrow \text{P}\{T \leq 100\} = 0.4443$ (Normal Distribution table)

(d) Higher

22.4-7.

(a) TRUE. The optimistic and pessimistic estimates lie at the extremes of what is possible, p.33.

(b) FALSE. The probability distribution is a Beta distribution, p.33.

(c) FALSE. The mean critical path will turn out to be the longest path in the project network.

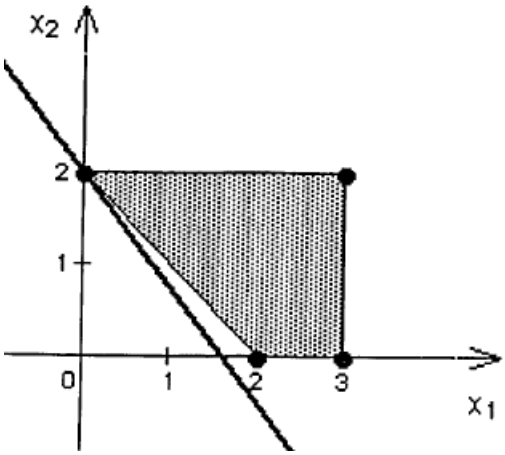
22.5-1.

		Length of Path	
Activity to Crash	Crash Cost	$A-C$	$B-D$
		14	16
B	$\$5,000$	14	15
B	$\$5,000$	14	15
D	$\$6,000$	14	14
C	$\$4,000$	13	14
D	$\$6,000$	13	13
C	$\$4,000$	12	13
D	$\$6,000$	12	12

22.5-2.

(a) Let x_A and x_C be the reduction in A and C respectively, due to crashing.

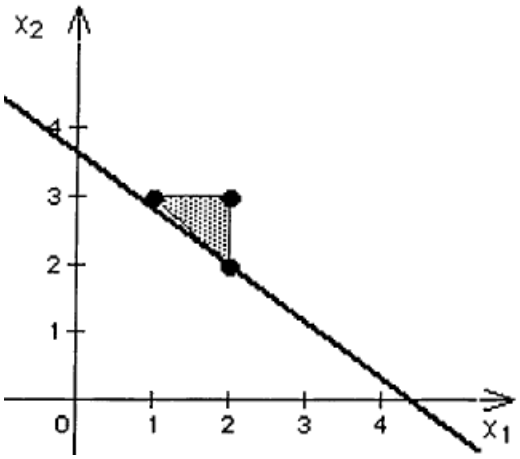
$$\begin{aligned} \text{minimize} \quad & C = 5000x_A + 4000x_C \\ \text{subject to} \quad & x_A \leq 3 \\ & x_C \leq 2 \\ & x_A + x_C \geq 2 \\ \text{and} \quad & x_A, x_C \geq 0 \end{aligned}$$



Optimal Solution: $(x_A, x_C) = (0, 2)$ and $C^* = 8,000$.

(b) Let x_B and x_D be the reduction in B and D respectively, due to crashing.

$$\begin{aligned} \text{minimize} \quad & C = 5000x_B + 6000x_D \\ \text{subject to} \quad & x_B \leq 2 \\ & x_D \leq 3 \\ & x_B + x_D \geq 4 \\ \text{and} \quad & x_B, x_D \geq 0 \end{aligned}$$



Optimal Solution: $(x_B, x_D) = (2, 2)$ and $C^* = 22,000$.

(c) Let x_A, x_B, x_C, and x_D be the reduction in the duration of A, B, C, and D respectively, due to crashing.

$$
\begin{aligned}
\text{minimize} \quad & C = 5000x_A + 5000x_B + 4000x_C + 6000x_D \\
\text{subject to} \quad & x_A \le 3 \\
& x_B \le 2 \\
& x_C \le 2 \\
& x_D \le 3 \\
& x_A + x_C \ge 2 \\
& x_B + x_D \ge 4 \\
\text{and} \quad & x_A, x_B, x_C, x_D \ge 0
\end{aligned}
$$

Optimal Solution: $(x_A, x_B, x_C, x_D) = (0, 2, 2, 2)$ and $C^* = 30,000$.

(d) Let x_j be the reduction in the duration of activity j due to crashing for $j = A, B, C, D$. Also let y_j denote the start time of activity j for $j = C, D$ and y_{FINISH} the project duration.

$$
\begin{aligned}
\text{minimize} \quad & C = 5000x_A + 5000x_B + 4000x_C + 6000x_D \\
\text{subject to} \quad & x_A \le 3, x_B \le 2, x_C \le 2, x_D \le 3 \\
& y_C \ge 0 + 8 - x_A \\
& y_D \ge 0 + 9 - x_B \\
& y_{\text{FINISH}} \ge y_C + 6 - x_C \\
& y_{\text{FINISH}} \ge y_D + 7 - x_D \\
& y_{\text{FINISH}} \le 12 \\
\text{and} \quad & x_A, x_B, x_C, x_D, y_C, y_D, y_{\text{FINISH}} \ge 0
\end{aligned}
$$

(e)

	Normal Time	Crash Time			Maximum Time Reduction	Crash Cost per Month			
Activity	(months)	(months)	Normal Cost	Crash Cost	(months)	Saved	Start Time	Time Reduction	Finish Time
A	8	5	$25,000	$40,000	3	$5,000	0	0	8
B	9	7	$20,000	$30,000	2	$5,000	0	2	7
C	6	4	$16,000	$24,000	2	$4,000	8	2	12
D	7	4	$27,000	$45,000	3	$6,000	7	2	12
									Max Time
					Project Completion Time (months)		12	<=	12
						Total Cost	$118,000		

(f) The solution found using LINGO agrees with the solution in (e), i.e., it is optimal to reduce the duration of activities B, C, and D by two months. Then the entire project takes 12 months and costs $25 + 30 + 24 + (27 + 12) = 118$ thousand dollars.

Variable	Value	Reduced Cost
XA	0.000000	0.000000
XB	2.000000	0.000000
XC	2.000000	0.000000
XD	2.000000	0.000000

Row	Slack or Surplus	Dual Price
1	30000.00	-1.000000
2	3.000000	0.000000
3	0.000000	1000.000
4	0.000000	1000.000
5	1.000000	0.000000
6	0.000000	-5000.000
7	0.000000	-6000.000

(g) Deadline of 11 months

	Normal Time	Crash Time			Maximum Time Reduction	Crash Cost per Month			
Activity	(months)	(months)	Normal Cost	Crash Cost	(months)	Saved	Start Time	Time Reduction	Finish Time
A	8	5	$25,000	$40,000	3	$5,000	0	1	7
B	9	7	$20,000	$30,000	2	$5,000	0	2	7
C	6	4	$16,000	$24,000	2	$4,000	7	2	11
D	7	4	$27,000	$45,000	3	$6,000	7	3	11	
									Max Time
					Project Completion Time (months)		11	<=	11
						Total Cost	$129,000		

Deadline of 13 months

	Normal Time	Crash Time			Maximum Time Reduction	Crash Cost per Month			
Activity	(months)	(months)	Normal Cost	Crash Cost	(months)	Saved	Start Time	Time Reduction	Finish Time
A	8	5	$25,000	$40,000	3	$5,000	0	0	8
B	9	7	$20,000	$30,000	2	$5,000	0	2	7
C	6	4	$16,000	$24,000	2	$4,000	8	1	13
D	7	4	$27,000	$45,000	3	$6,000	7	1	13	
									Max Time
					Project Completion Time (months)		13	<=	13
						Total Cost	$108,000		

22.5-3.

(a)

Activity to Crash	Crash Cost	Length of Path B-D
		50
B	$10,000	49
B	$10,000	48
B	$10,000	47

(b)

Activity to Crash	Crash Cost	Length of Path A-C-E-F
		51
C	$10,000	50
C	$10,000	49
C	$10,000	48
E	$15,000	47

(c)

Activity	Normal Time (days)	Crash Time (days)	Normal Cost	Crash Cost	Maximum Time Reduction (days)	Crash Cost per Day Saved	Start Time	Time Reduction	Finish Time
A	12	9	$210,000	$270,000	3	$20,000	0	0	12
B	23	18	$410,000	$460,000	5	$10,000	0	3	20
C	15	12	$290,000	$320,000	3	$10,000	12	3	24
D	27	21	$440,000	$500,000	6	$10,000	20	0	47
E	18	14	$350,000	$410,000	4	$15,000	24	1	41
F	6	4	$160,000	$210,000	2	$25,000	41	0	47
									Max Time
					Project Completion Time (days)		47	<=	47
						Total Cost	$1,935,000		

22.5-4.

(a)

Activity	ES	EF	LS	LF	Slack	Critical Path
Start	0	0	0	0	0	Yes
A	0	3	0	3	0	Yes
B	3	7	4	8	1	No
C	3	8	3	8	0	Yes
D	7	10	9	12	2	No
E	8	12	8	12	0	Yes
Finish	12	12	12	12	0	Yes

Critical Path: Start $\rightarrow A \rightarrow C \rightarrow E \rightarrow$ Finish
Total Duration: 12 weeks

(b) $7,834 is saved by the new plan given below.

Activity to Crash	Crash Cost	Length of Path		
		$A-B-D$	$A-B-E$	$A-C-E$
		10	11	12
C	$\$1,333$	10	11	11
E	$\$2,500$	10	10	10
D & E	$\$4,000$	9	9	9
B & C	$\$4,333$	8	8	8

Activity	Duration	Cost
A	3 weeks	$\$54,000$
B	3 weeks	$\$65,000$
C	3 weeks	$\$58,666$
D	2 weeks	$\$41,500$
E	2 weeks	$\$80,000$

(c)

Activity	Normal Time (weeks)	Crash Time (weeks)	Normal Cost	Crash Cost	Maximum Time Reduction (weeks)	Crash Cost per Week Saved	Start Time	Time Reduction	Finish Time
A	3	2	$54,000	$60,000	1	$6,000	0	0	3
B	4	3	$62,000	$65,000	1	$3,000	4	0	8
C	5	2	$66,000	$70,000	3	$1,333	3	0	8
D	3	1	$40,000	$43,000	2	$1,500	9	0	12
E	4	2	$75,000	$80,000	2	$2,500	8	0	12
									Max Time
						Project Completion Time (weeks)	12	<=	12
						Total Cost	$297,000		

Activity	Normal Time (weeks)	Crash Time (weeks)	Normal Cost	Crash Cost	Maximum Time Reduction (weeks)	Crash Cost per Week Saved	Start Time	Time Reduction	Finish Time
A	3	2	$54,000	$60,000	1	$6,000	0	0	3
B	4	3	$62,000	$65,000	1	$3,000	3	0	7
C	5	2	$66,000	$70,000	3	$1,333	3	1	7
D	3	1	$40,000	$43,000	2	$1,500	8	0	11
E	4	2	$75,000	$80,000	2	$2,500	7	0	11
									Max Time
						Project Completion Time (weeks)	11	<=	11
						Total Cost	$298,333		

Activity	Normal Time (weeks)	Crash Time (weeks)	Normal Cost	Crash Cost	Maximum Time Reduction (weeks)	Crash Cost per Week Saved	Start Time	Time Reduction	Finish Time
A	3	2	$54,000	$60,000	1	$6,000	0	0	3
B	4	3	$62,000	$65,000	1	$3,000	3	0	7
C	5	2	$66,000	$70,000	3	$1,333	3	1	7
D	3	1	$40,000	$43,000	2	$1,500	7	0	10
E	4	2	$75,000	$80,000	2	$2,500	7	1	10
									Max Time
						Project Completion Time (weeks)	10	<=	10
						Total Cost	$300,833		

Activity	Normal Time (weeks)	Crash Time (weeks)	Normal Cost	Crash Cost	Maximum Time Reduction (weeks)	Crash Cost per Week Saved	Start Time	Time Reduction	Finish Time
A	3	2	$54,000	$60,000	1	$6,000	0	0	3
B	4	3	$62,000	$65,000	1	$3,000	3	0	7
C	5	2	$66,000	$70,000	3	$1,333	3	1	7
D	3	1	$40,000	$43,000	2	$1,500	7	1	9
E	4	2	$75,000	$80,000	2	$2,500	7	2	9
									Max Time
						Project Completion Time (weeks)	9	<=	9
						Total Cost	$304,833		

	Normal	Crash			Maximum Time	Crash Cost			
	Time	Time	Normal	Crash	Reduction	per Week	Start	Time	Finish
Activity	(weeks)	(weeks)	Cost	Cost	(weeks)	Saved	Time	Reduction	Time
A	3	2	$54,000	$60,000	1	$6,000	0	0	3
B	4	3	$62,000	$65,000	1	$3,000	3	1	6
C	5	2	$66,000	$70,000	3	$1,333	3	2	6
D	3	1	$40,000	$43,000	2	$1,500	6	1	8
E	4	2	$75,000	$80,000	2	$2,500	6	2	8
									Max Time
						Project Completion Time (weeks)	8	<=	8
						Total Cost	$309,167		

Crash to 8 weeks.

22.5-5.

(a) Let x_j be the reduction in the duration of activity j and y_j be the start time of activity j.

minimize $C = 6x_A + 12x_B + 4x_C + 6.67x_D + 10x_E + 7.33x_F + 5.75x_G + 8x_H$

subject to
$0 \le x_A \le 2 \quad 0 \le x_B \le 1 \quad 0 \le x_C \le 2 \quad 0 \le x_D \le 3$
$0 \le x_E \le 1 \quad 0 \le x_F \le 3 \quad 0 \le x_G \le 4 \quad 0 \le x_H \le 2$
$y_A + 5 - x_A \le y_C \qquad y_A + 5 - x_A \le y_D$
$y_B + 3 - x_B \le y_E \qquad y_B + 3 - x_B \le y_F$
$y_C + 4 - x_C \le y_G \qquad y_D + 6 - x_D \le y_H$
$y_E + 5 - x_E \le y_G \qquad y_F + 7 - x_F \le y_H$
$y_G + 9 - x_G \le y_{\text{FINISH}} \qquad y_H + 8 - x_H \le y_{\text{FINISH}}$
$0 \le y_{\text{FINISH}} \le 15$
$y_j \ge 0$

(b) Finish Time: 15 weeks, total crashing cost: $45.75 million, total cost: $259.75 million.

Activity	Normal Time	Crash Time	Normal Cost	Crash Cost	Maximum Time Reduction	Crash Cost per Week Saved	Start Time	Time Reduction	Finish Time
A	5	3	24	36	2	6.00	0	2	3
B	3	2	13	25	1	12.00	0	1	2
C	4	2	21	29	2	4.00	3	0	7
D	6	3	30	50	3	6.67	3	0	9
E	5	4	26	36	1	10.00	2	0	7
F	7	4	35	57	3	7.33	2	0	9
G	9	5	30	53	4	5.75	7	1	15
H	8	6	35	51	2	8.00	9	2	15

22.5-6.

(a) Let x_j be the reduction in the duration of activity j and y_j be the start time of activity j.

minimize $C = 5x_A + 7x_B + 8x_C + 4x_D + 5x_E + 6x_F + 3x_G + 4x_H + 9x_I + 2x_J$

subject to $0 \le x_A \le 4 \quad 0 \le x_B \le 3 \quad 0 \le x_C \le 5 \quad 0 \le x_D \le 3 \quad 0 \le x_E \le 5$
$0 \le x_F \le 7 \quad 0 \le x_G \le 2 \quad 0 \le x_H \le 3 \quad 0 \le x_I \le 4 \quad 0 \le x_J \le 2$
$y_A + 32 - x_A \le y_C \qquad y_B + 28 - x_B \le y_D$
$y_B + 28 - x_B \le y_E \qquad y_B + 28 - x_B \le y_F$
$y_C + 36 - x_C \le y_J \qquad y_D + 16 - x_D \le y_G$
$y_E + 32 - x_E \le y_H \qquad y_E + 32 - x_E \le y_I$
$y_F + 54 - x_F \le y_J \qquad y_G + 17 - x_G \le y_H$
$y_G + 17 - x_G \le y_I \qquad y_H + 20 - x_H \le y_{\text{FINISH}}$
$y_I + 34 - x_I \le y_{\text{FINISH}} \qquad y_J + 18 - x_J \le y_{\text{FINISH}}$
$0 \le y_{\text{FINISH}} \le 92$
$y_j \ge 0$

(b) Finish Time: 92 weeks, total crashing cost: \$43 million, total cost: \$1.388 billion.

Activity	Normal Time	Crash Time	Normal Cost	Crash Cost	Maximum Time Reduction	Crash Cost per Week Saved	Start Time	Time Reduction	Finish Time
A	32	28	160	180	4	5	8	0	40
B	28	25	125	146	3	7	0	3	25
C	36	31	170	210	5	8	40	0	76
D	16	13	60	72	3	4	25	0	41
E	32	27	135	160	5	5	26	0	58
F	54	47	215	257	7	6	25	3	76
G	17	15	90	96	2	3	41	0	58
H	20	17	120	132	3	4	58	0	78
I	34	30	190	226	4	9	58	0	92
J	18	16	80	84	2	2	76	2	92

22.6-1.

(a)

Activity	ES	EF
Start	0	0
A	0	3
B	3	6
C	3	6
D	6	8
E	6	8
Finish	8	8

Total Duration: 8 weeks

(b) - (c) - (d)

Activity	Estimated Duration (weeks)	Estimated Cost	Start Time	Cost Per Week of Its Duration	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
A	3	$54,000	0	$18,000	$18,000	$18,000	$18,000	$0	$0	$0	$0	$0
B	3	$65,000	3	$21,667	$0	$0	$0	$21,667	$21,667	$21,667	$0	$0
C	3	$68,667	3	$22,889	$0	$0	$0	$22,889	$22,889	$22,889	$0	$0
D	2	$41,500	6	$20,750	$0	$0	$0	$0	$0	$0	$20,750	$20,750
E	2	$80,000	6	$40,000	$0	$0	$0	$0	$0	$0	$40,000	$40,000
				Weekly Project Cost	$18,000	$18,000	$18,000	$44,556	$44,556	$44,556	$60,750	$60,750
				Cumulative Project Cost	$18,000	$36,000	$54,000	$98,556	$143,111	$187,667	$248,417	$309,167

(e)

Activity	Budgeted Cost	Percent Completed	Value Completed	Actual Cost To Date	Cost Overrun To Date
A	$54,000	100%	$54,000	$65,000	$11,000
B	$65,000	100%	$65,000	$55,000	-$10,000
C	$68,666	33%	$22,660	$44,000	$21,340
Total	$187,666		$141,660	$164,000	$22,340

Michael should concentrate his efforts on activity C, since it is not yet completed.

22.6-2.

(a)

Activity	ES	EF	LS	LF	Slack
Start	0	0	0	0	0
A	0	6	0	6	0
B	0	2	4	6	4
C	6	10	9	13	3
D	6	11	6	11	0
E	10	17	13	20	3
F	11	20	11	20	0
Finish	20	20	20	20	0

The earliest finish time for this project is 20 weeks.

(b)

Activity	Estimated Duration (weeks)	Estimated Cost ($thousands)	Start Time	Cost Per Week of Its Duration ($thousands)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
					all costs in $thousands							
A	6	420	0	70	70	70	70	70	70	70	0	0
B	2	180	0	90	90	90	0	0	0	0	0	0
C	4	540	6	135	0	0	0	0	0	0	135	135
D	5	360	6	72	0	0	0	0	0	0	72	72
E	7	590	10	84.286	0	0	0	0	0	0	0	0
F	9	630	11	70	0	0	0	0	0	0	0	0
				Weekly Project Cost ($thousands)	160	160	70	70	70	70	207	207
				Cumulative Project Cost ($thousands)	160	320	390	460	530	600	807	1014

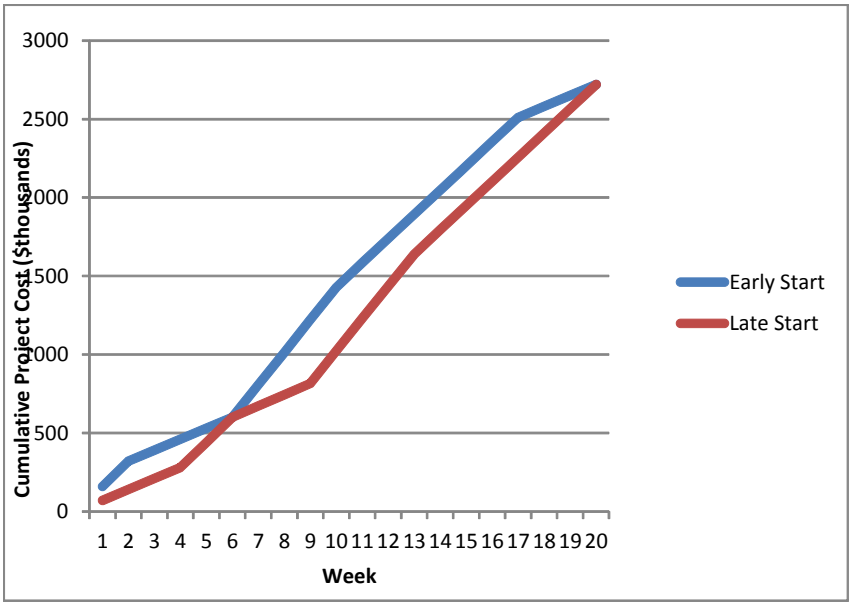
Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
135	135	0	0	0	0	0	0	0	0	0	0
72	72	72	0	0	0	0	0	0	0	0	0
0	0	84.29	84.29	84.29	84.29	84.29	84.29	84.29	0	0	0
0	0	0	70	70	70	70	70	70	70	70	70
207	207	156.3	154.3	154.3	154.3	154.3	154.3	154.3	70	70	70
1221	1428	1584	1739	1893	2047	2201	2356	2510	2580	2650	2720

(c)

	Estimated Duration	Estimated Cost	Start	Cost Per Week of Its Duration			all costs in $thousands					
Activity	(weeks)	($thousands)	Time	($thousands)	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8
A	6	420	0	70	70	70	70	70	70	70	0	0
B	2	180	4	90	0	0	0	0	90	90	0	0
C	4	540	9	135	0	0	0	0	0	0	0	0
D	5	360	6	72	0	0	0	0	0	0	72	72
E	7	590	13	84.286	0	0	0	0	0	0	0	0
F	9	630	11	70	0	0	0	0	0	0	0	0
		Weekly Project Cost ($thousands)			70	70	70	70	160	160	72	72
		Cumulative Project Cost ($thousands)			70	140	210	280	440	600	672	744

Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15	Week 16	Week 17	Week 18	Week 19	Week 20
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	135	135	135	135	0	0	0	0	0	0	0
72	72	72	0	0	0	0	0	0	0	0	0
0	0	0	0	0	84.29	84.29	84.29	84.29	84.29	84.29	84.29
0	0	0	70	70	70	70	70	70	70	70	70
72	207	207	205	205	154.3	154.3	154.3	154.3	154.3	154.3	154.3
816	1023	1230	1435	1640	1794	1949	2103	2257	2411	2566	2720

(d)



(e)

Activity	Budgeted Cost	Percent Completed	Value Completed	Actual Cost To Date	Cost Overrun To Date
A	$420,000	50%	$210,000	$200,000	-$10,000
B	$180,000	100%	$180,000	$200,000	$20,000
D	$360,000	50%	$180,000	$210,000	$30,000
Total	$960,000		$570,000	$610,000	$40,000

The project manager should focus attention on activity *D*, since it is not yet finished and they are running over budget.

22.6-3.

(a)

	Estimated	Estimated		Cost Per Week			all costs in $thousands					
	Duration	Cost	Start	of Its Duration	Week	Week	Week	Week	Week	Week	Week	Week
Activity	(weeks)	($thousands)	Time	($thousands)	1	2	3	4	5	6	7	8
A	6	180	0	30	30	30	30	30	30	30	0	0
B	3	75	0	25	25	25	25	0	0	0	0	0
C	4	120	0	30	30	30	30	30	0	0	0	0
D	4	140	6	35	0	0	0	0	0	0	35	35
E	7	175	3	25	0	0	0	25	25	25	25	25
F	4	80	4	20	0	0	0	0	20	20	20	20
G	6	210	4	35	0	0	0	0	35	35	35	35
H	3	45	10	15	0	0	0	0	0	0	0	0
I	5	125	6	25	0	0	0	0	0	0	25	25
J	4	100	10	25	0	0	0	0	0	0	0	0
K	3	60	8	20	0	0	0	0	0	0	0	0
L	5	50	10	10	0	0	0	0	0	0	0	0
M	6	90	14	15	0	0	0	0	0	0	0	0
N	5	150	15	30	0	0	0	0	0	0	0	0
		Weekly Project Cost ($thousands)			85	85	85	85	110	110	140	140
		Cumulative Project Cost ($thousands)			85	170	255	340	450	560	700	840

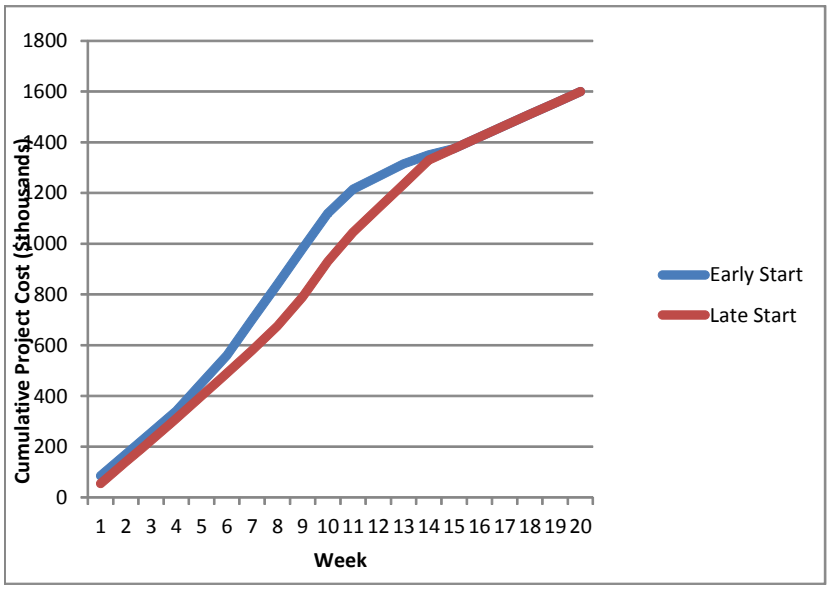
Week	Week	Week	Week	Week	Week	Week	Week	Week	Week	Week	Week
9	10	11	12	13	14	15	16	17	18	19	20
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
35	35	0	0	0	0	0	0	0	0	0	0
25	25	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
35	35	0	0	0	0	0	0	0	0	0	0
0	0	15	15	15	0	0	0	0	0	0	0
25	25	25	0	0	0	0	0	0	0	0	0
0	0	25	25	25	25	0	0	0	0	0	0
20	20	20	0	0	0	0	0	0	0	0	0
0	0	10	10	10	10	10	0	0	0	0	0
0	0	0	0	0	0	15	15	15	15	15	15
0	0	0	0	0	0	0	30	30	30	30	30
140	140	95	50	50	35	25	45	45	45	45	45
980	1120	1215	1265	1315	1350	1375	1420	1465	1510	1555	1600

(b)

	Estimated	Estimated		Cost Per Week			all costs in $thousands					
	Duration	Cost	Start	of Its Duration	Week	Week	Week	Week	Week	Week	Week	Week
Activity	(weeks)	($thousands)	Time	($thousands)	1	2	3	4	5	6	7	8
A	6	180	1	30	0	30	30	30	30	30	30	0
B	3	75	0	25	25	25	25	0	0	0	0	0
C	4	120	0	30	30	30	30	30	0	0	0	0
D	4	140	7	35	0	0	0	0	0	0	0	35
E	7	175	3	25	0	0	0	25	25	25	25	25
F	4	80	8	20	0	0	0	0	0	0	0	0
G	6	210	4	35	0	0	0	0	35	35	35	35
H	3	45	11	15	0	0	0	0	0	0	0	0
I	5	125	9	25	0	0	0	0	0	0	0	0
J	4	100	10	25	0	0	0	0	0	0	0	0
K	3	60	12	20	0	0	0	0	0	0	0	0
L	5	50	10	10	0	0	0	0	0	0	0	0
M	6	90	14	15	0	0	0	0	0	0	0	0
N	5	150	15	30	0	0	0	0	0	0	0	0
		Weekly Project Cost ($thousands)			55	85	85	85	90	90	90	95
		Cumulative Project Cost ($thousands)			55	140	225	310	400	490	580	675

Week	Week	Week	Week	Week	Week	Week	Week	Week	Week	Week	Week
9	10	11	12	13	14	15	16	17	18	19	20
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0
35	35	35	0	0	0	0	0	0	0	0	0
25	25	0	0	0	0	0	0	0	0	0	0
20	20	20	20	0	0	0	0	0	0	0	0
35	35	0	0	0	0	0	0	0	0	0	0
0	0	0	15	15	15	0	0	0	0	0	0
0	25	25	25	25	25	0	0	0	0	0	0
0	0	25	25	25	25	0	0	0	0	0	0
0	0	0	0	20	20	20	0	0	0	0	0
0	0	10	10	10	10	10	0	0	0	0	0
0	0	0	0	0	0	15	15	15	15	15	15
0	0	0	0	0	0	0	30	30	30	30	30
115	140	115	95	95	95	45	45	45	45	45	45
790	930	1045	1140	1235	1330	1375	1420	1465	1510	1555	1600

(c)



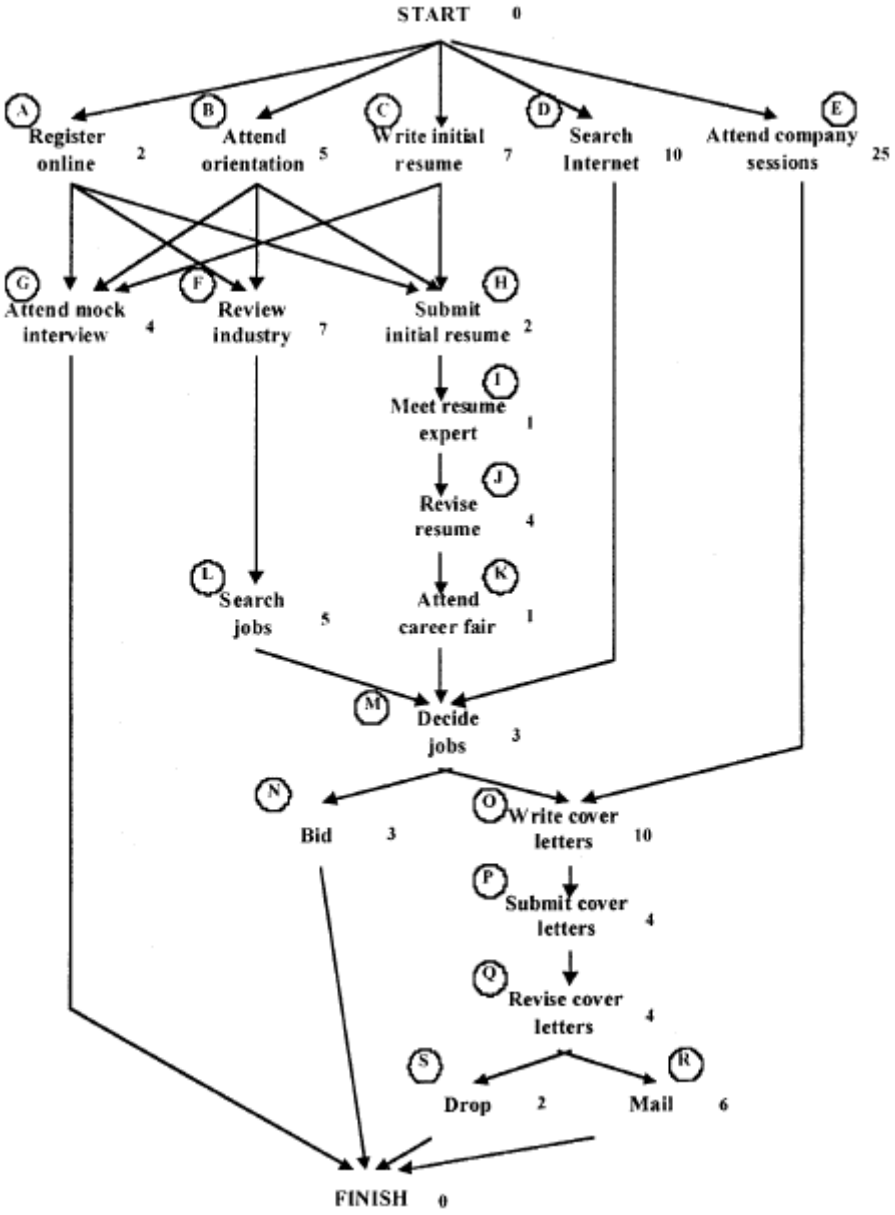
(d)

Activity	Budgeted Cost	Percent Completed	Value Completed	Actual Cost To Date	Cost Overrun To Date
A	$180,000	100%	$180,000	$190,000	$10,000
B	$75,000	100%	$75,000	$70,000	-$5,000
C	$120,000	100%	$120,000	$150,000	$30,000
D	$140,000	40%	$56,000	$70,000	$14,000
E	$175,000	50%	$87,500	$100,000	$12,500
F	$80,000	60%	$48,000	$45,000	-$3,000
G	$210,000	25%	$52,500	$50,000	-$2,500
I	$125,000	20%	$25,000	$35,000	$10,000
Total	$1,105,000		$644,000	$710,000	$66,000

The project manager should investigate activities D, E and I, since they are not yet finished and they are running over budget.

CASE 22.1 "School's Out Forever ..." Alice Cooper

(a)



The estimated project duration equals the length of the longest path in the project network. To calculate this length, we use the layout of the Excel spreadsheets for Reliable's project in this chapter. We need to modify the spreadsheet to reflect the network unique to this case.

		Time	Week				Slack	
Activity	Description	(days)	ES	EF	LS	LF	(days)	Critical?
A	Register online	2	0	2	8	10	8	No
B	Attend orientation	5	0	5	5	10	5	No
C	Write initial resume	7	0	7	7	14	7	No
D	Search internet	10	0	10	12	22	12	No
E	Attend company sessions	25	0	25	0	25	0	Yes
F	Review industry, etc.	7	5	12	10	17	5	No
G	Attend mock interview	4	7	11	45	49	38	No
H	Submit initial resume	2	7	9	14	16	7	No
I	Meet resume expert	1	9	10	16	17	7	No
J	Revise resume	4	10	14	17	21	7	No
K	Attend career fair	1	14	15	21	22	7	No
L	Search jobs	5	12	17	17	22	5	No
M	Decide jobs	3	17	20	22	25	5	No
N	Bid	3	20	23	46	49	26	No
O	Write cover letters	10	25	35	25	35	0	Yes
P	Submit cover letters	4	35	39	35	39	0	Yes
Q	Revise cover letters	4	39	43	39	43	0	Yes
R	Mail	6	43	49	43	49	0	Yes
S	Drop	2	43	45	47	49	4	No
	Project Duration (days)			49				

Brent can start the interviews in 49 days. The critical steps in the process are: Start $\rightarrow E \rightarrow O \rightarrow P \rightarrow Q \rightarrow R \rightarrow$ Finish.

(b) We substitute first the pessimistic, then the optimistic estimates for the time values used in part (a).

Pessimistic Estimates:

		Time	Week				Slack	
Activity	Description	(days)	ES	EF	LS	LF	(days)	Critical?
A	Register online	4	0	4	6	10	6	No
B	Attend orientation	10	0	10	0	10	0	Yes
C	Write initial resume	14	0	14	4	18	4	No
D	Search internet	12	0	12	20	32	20	No
E	Attend company sessions	30	0	30	6	36	6	No
F	Review industry, etc.	12	10	22	10	22	0	Yes
G	Attend mock interview	8	14	22	66	74	52	No
H	Submit initial resume	6	14	20	18	24	4	No
I	Meet resume expert	1	20	21	24	25	4	No
J	Revise resume	6	21	27	25	31	4	No
K	Attend career fair	1	27	28	31	32	4	No
L	Search jobs	10	22	32	22	32	0	Yes
M	Decide jobs	4	32	36	32	36	0	Yes
N	Bid	8	36	44	66	74	30	No
O	Write cover letters	12	36	48	36	48	0	Yes
P	Submit cover letters	7	48	55	48	55	0	Yes
Q	Revise cover letters	9	55	64	55	64	0	Yes
R	Mail	10	64	74	64	74	0	Yes
S	Drop	3	64	67	71	74	7	No
	Project Duration (days)			74				

Under the worst-case scenario, Brent will require 74 days before he is ready to start interviewing. The critical path is:

Start $\rightarrow B \rightarrow F \rightarrow L \rightarrow M \rightarrow O \rightarrow P \rightarrow Q \rightarrow R \rightarrow$ Finish.

Optimistic Estimates:

		Time	Week				Slack	
Activity	Description	(days)	ES	EF	LS	LF	(days)	Critical?
A	Register online	1	0	1	9	10	9	No
B	Attend orientation	3	0	3	7	10	7	No
C	Write initial resume	5	0	5	7	12	7	No
D	Search internet	7	0	7	11	18	11	No
E	Attend company sessions	20	0	20	0	20	0	Yes
F	Review industry, etc.	5	3	8	10	15	7	No
G	Attend mock interview	3	5	8	29	32	24	No
H	Submit initial resume	1	5	6	12	13	7	No
I	Meet resume expert	1	6	7	13	14	7	No
J	Revise resume	3	7	10	14	17	7	No
K	Attend career fair	1	10	11	17	18	7	No
L	Search jobs	3	8	11	15	18	7	No
M	Decide jobs	2	11	13	18	20	7	No
N	Bid	2	13	15	30	32	17	No
O	Write cover letters	3	20	23	20	23	0	Yes
P	Submit cover letters	2	23	25	23	25	0	Yes
Q	Revise cover letters	3	25	28	25	28	0	Yes
R	Mail	4	28	32	28	32	0	Yes
S	Drop	1	28	29	31	32	3	No
	Project Duration (days)			32				

Under the best-case scenario, Brent will require 32 days before he is ready to begin interviewing. The critical path remains the same as in (a).

(c) The mean critical path is the path in the project network that would be critical path if the duration of each activity equals its mean. To compute the mean duration of each activity, we use the Excel spreadsheet named PERT.

	Time Estimates			On Mean					
Activity	o	m	p	Critical Path	μ	σ^2			
A	1	2	4		2.17	0.25		Mean Critical	
B	3	5	10		5.5	1.36		Path	
C	5	7	14		7.83	2.25		μ =	49.333
D	7	10	12		9.83	0.69		σ^2 =	7.722
E	20	25	30	*	25	2.78			
F	5	7	12		7.5	1.36		P(T≤d) =	0.99994
G	3	4	8		4.5	0.69		where	
H	1	2	6		2.5	0.69		d =	60
I	1	1	1		1	0			
J	3	4	6		4.17	0.25			
K	1	1	1		1	0			
L	3	5	10		5.5	1.36			
M	2	3	4		3	0.11			
N	2	3	8		3.67	1			
O	3	10	12	*	9.17	2.25			
P	2	4	7	*	4.17	0.69			
Q	3	4	9	*	4.67	1			
R	4	6	10	*	6.33	1			
S	1	2	3		2	0.11			

Now, substitute the mean duration of each activity for the time values.

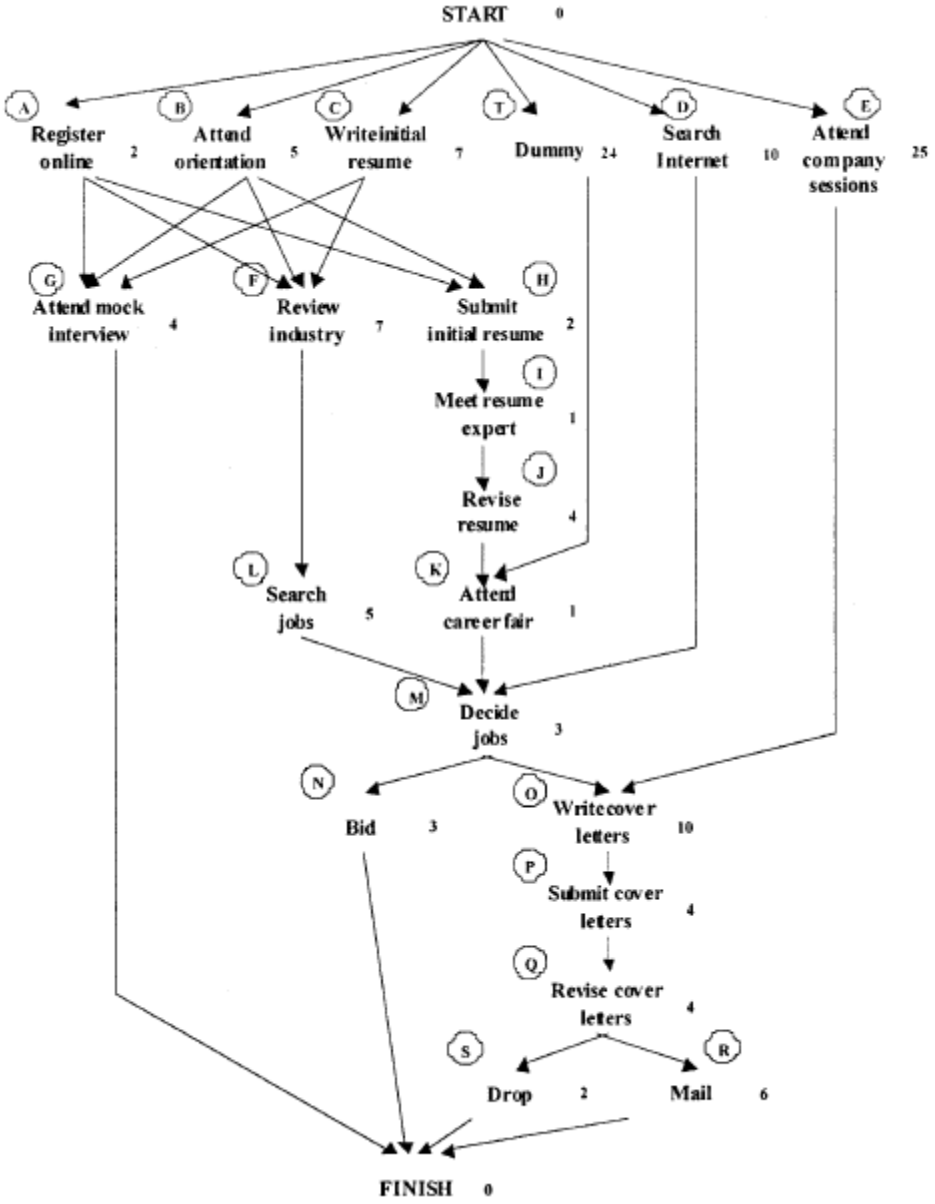
		Time	Week				Slack	
Activity	Description	(days)	ES	EF	LS	LF	(days)	Critical?
A	Register online	2.167	0	2.1667	6.8333	9	6.8333	No
B	Attend orientation	5.5	0	5.5	3.5	9	3.5	No
C	Write initial resume	7.833	0	7.8333	5.5	13.333	5.5	No
D	Search internet	9.833	0	9.8333	12.167	22	12.167	No
E	Attend company sessions	25	0	25	0	25	0	Yes
F	Review industry, etc.	7.5	5.5	13	9	16.5	3.5	No
G	Attend mock interview	4.5	7.8333	12.333	44.833	49.333	37	No
H	Submit initial resume	2.5	7.8333	10.333	13.333	15.833	5.5	No
I	Meet resume expert	1	10.333	11.333	15.833	16.833	5.5	No
J	Revise resume	4.167	11.333	15.5	16.833	21	5.5	No
K	Attend career fair	1	15.5	16.5	21	22	5.5	No
L	Search jobs	5.5	13	18.5	16.5	22	3.5	No
M	Decide jobs	3	18.5	21.5	22	25	3.5	No
N	Bid	3.667	21.5	25.167	45.667	49.333	24.167	No
O	Write cover letters	9.167	25	34.167	25	34.167	0	Yes
P	Submit cover letters	4.167	34.167	38.333	34.167	38.333	0	Yes
Q	Revise cover letters	4.667	38.333	43	38.333	43	0	Yes
R	Mail	6.333	43	49.333	43	49.333	0	Yes
S	Drop	2	43	45	47.333	49.333	4.3333	No
	Project Duration (days)			49.333				

The mean critical path is the same as in (a). To compute the variance of the project duration, we use the PERT template again.

The mean and the variance of the mean critical path are $\mu = 49.333$ and $\sigma_2 = 7.722$.

(d) We use the PERT template as in part (c). Brent will be ready for his interviews within 60 days with probability 99.994%.

(e) The earliest start time for the career fair is day 24 and the career fair itself still lasts one day. To ensure that the earliest start time for the career fair is day 24, we add a dummy node T with duration 24 days to the project network, directly following the START node and preceding the career fair node K.



(f) To obtain the mean critical path for the new network and the probability that Brent will complete the project within 60 days, we first use the PERT template to compute the mean duration for each activity. We add the new node T to the list of activities.

	Time Estimates			On Mean		
Activity	o	m	p	Critical Path	μ	σ^2
A	1	2	4		2.17	0.25
B	3	5	10		5.5	1.36
C	5	7	14		7.83	2.25
D	7	10	12		9.83	0.69
E	20	25	30		25	2.78
F	5	7	12		7.5	1.36
G	3	4	8		4.5	0.69
H	1	2	6		2.5	0.69
I	1	1	1		1	0
J	3	4	6		4.17	0.25
K	1	1	1	*	1	0
L	3	5	10		5.5	1.36
M	2	3	4	*	3	0.11
N	2	3	8		3.67	1
O	3	10	12	*	9.17	2.25
P	2	4	7	*	4.17	0.69
Q	3	4	9	*	4.67	1
R	4	6	10	*	6.33	1
S	1	2	3		2	0.11
T	24	24	24	*	24	0

We next substitute these mean duration values for the time values to find the critical path. We need to add node T to the spreadsheet used in (a).

		Time	Week				Slack	
Activity	Description	(days)	ES	EF	LS	LF	(days)	Critical?
A	Register online	2.167	0	2.1667	9.8333	12	9.8333	No
B	Attend orientation	5.5	0	5.5	6.5	12	6.5	No
C	Write initial resume	7.833	0	7.8333	8.5	16.333	8.5	No
D	Search internet	9.833	0	9.8333	15.167	25	15.167	No
E	Attend company sessions	25	0	25	3	28	3	No
F	Review industry, etc.	7.5	5.5	13	12	19.5	6.5	No
G	Attend mock interview	4.5	7.8333	12.333	47.833	52.333	40	No
H	Submit initial resume	2.5	7.8333	10.333	16.333	18.833	8.5	No
I	Meet resume expert	1	10.333	11.333	18.833	19.833	8.5	No
J	Revise resume	4.167	11.333	15.5	19.833	24	8.5	No
K	Attend career fair	1	24	25	24	25	0	Yes
L	Search jobs	5.5	13	18.5	19.5	25	6.5	No
M	Decide jobs	3	25	28	25	28	0	Yes
N	Bid	3.667	28	31.667	48.667	52.333	20.667	No
O	Write cover letters	9.167	28	37.167	28	37.167	0	Yes
P	Submit cover letters	4.167	37.167	41.333	37.167	41.333	0	Yes
Q	Revise cover letters	4.667	41.333	46	41.333	46	0	Yes
R	Mail	6.333	46	52.333	46	52.333	0	Yes
S	Drop	2	46	48	50.333	52.333	4.3333	No
T	Dummy	24	0	24	0	24	0	Yes
	Project Duration (days)			52.333				

The mean project duration is now 52.33 days and the new mean critical path is:

Start $\rightarrow T \rightarrow K \rightarrow M \rightarrow O \rightarrow P \rightarrow Q \rightarrow R \rightarrow$ Finish.

We specify this new critical path in the PERT spreadsheet to obtain the probability that Brent will complete the project within 60 days.

Mean Critical Path	
$\mu =$	52.333
$\sigma^2 =$	5.056
P(T≤d) =	0.99967
where	
d =	60

Brent will be ready for his interviews within 60 days with probability 99.967%, which is slightly less than the probability computed in part (d). This decrease is a result of the increase in the mean project duration. However, since the variance of the project duration is smaller than the one found in (d), the probability decreases only slightly.