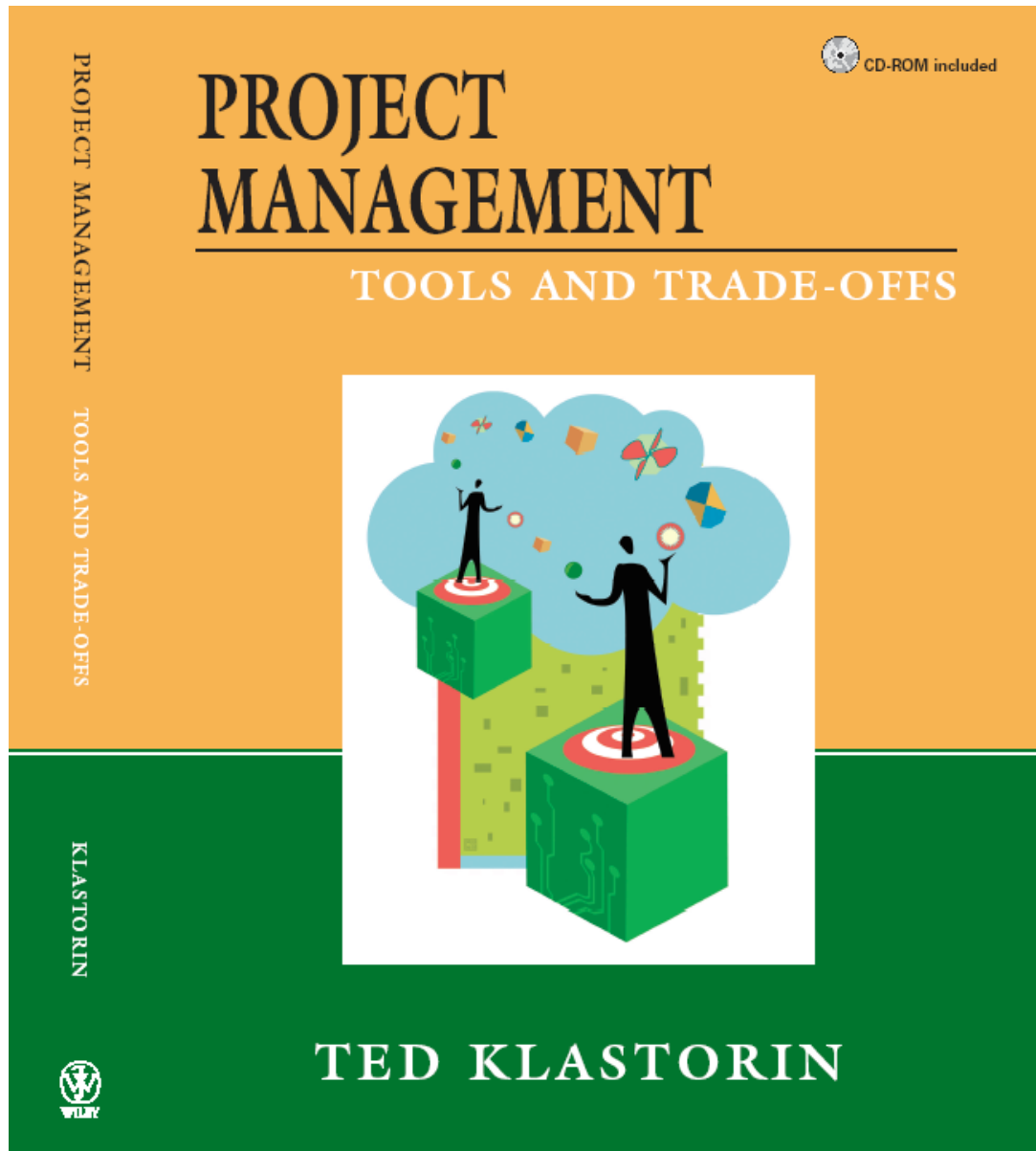


Instructor's Guide *for*



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Preface

This book is intended for use in undergraduate and graduate project management (PM) elective courses at most universities and colleges. I find that using the material in this text along with other case studies and occasional outside speakers results in a meaningful and substantive PM course. This book is written so that it can be used with a minimum number of prerequisites (I assume that the student has had some basic exposure to linear programming, understands basic concepts of probability and statistics, and is familiar with basic spreadsheets).

I have generally used the text material along with a number of (field) case studies. I try to select those cases that reinforce the trade-offs discussed in the book and bring real-world issues, complexities, and behavioral aspects into the classroom. Most of the case studies I have used are offered by Harvard Business School Publishing or the European Case Clearing House. A good example of such a case is the Applied Materials case (HBS Publishing #N9-692-078). This case study raises important issues relating to new product development projects, including the issues of how to design incentives for project team members, project compression, risk management (how to relate to competitive rumors), and technology management.

In addition, I have found that careful selection of outside speakers can reinforce many of the concepts emphasized in the book and give those students who have not been directly involved in managing a complex project a good sense of the difficulties and issues involved in managing complex real-world projects.

This instructor's guide is designed to assist you in your efforts to develop a substantive PM course. Please feel free to contact me (at tedk@u.washington.edu) if you have any questions or if I can provide any additional information.

TDK
Sept, 2003

Chapter 1: Introduction to Project Management

Chapter 1 is an introductory chapter designed to support the importance of studying project management methods and tools. The main points emphasized in this chapter include:

- 1) reasons why the study and understanding of formal project management tools has become so important (including some case studies),
- 2) definition of a project and how projects differ from other forms of management endeavors,
- 3) a brief history of project management,
- 4) a taxonomy of projects and how and why projects differ so much, and
- 5) a description of the overall job of managing complex projects.

Notes on Study Problems:

There are no right or wrong answers to the study questions posed in Chapter 1; these problems are designed to stimulate student thinking about important issues faced by project managers and the corresponding trade-offs that must be made. Problem #2 is designed to motivate student thinking about the formation and management of project teams and raises questions that are addressed in the third chapter. Generally, most folks think that project teams should reflect a diversity of experiences, background, and training...but too much diversity can lead to dissension and paralysis of the project team. Likewise, problem #3 introduces concepts relating to matrix organizations (which is covered in the third chapter) and the resulting trade-offs that result.

Problem #4 introduces the issue of project selection that is discussed in some detail in the second chapter. Again, the intent of this question (and, for that matter, all the material in the first chapter) is to motivate the student to think about some of the important issues discussed later in the text.

Omitted reference at the end of Chapter 1:

Yeo, Khim T. (1999) "Sources of Failure in Information Systems Implementation", Working Paper, Workshop on Risk Management in Supply Chain Management, Industrial Engineering Program, University of Washington, Seattle, WA.

Chapter 2: Project Initiation, Selection, and Planning

Chapter 2 covers two important topics: (1) project initiation and selection, and (2) project planning. With respect to the former, the chapter presents several methods used to evaluate and select projects (including numerical methods, and ranking and scoring methods), discusses the importance of options thinking when selecting a project, and the importance of viewing the project portfolio as one would view any investment portfolio. I have found that this section and topic can be easily covered in a (1 hour and 50 minute) class and is generally very well received by students.

Once a project is selected, the issue of how to define and plan the project emerges. Issues to emphasize here include the definition of tasks/activities using a Work Breakdown Structure (WBS) and estimating the duration and cost of these tasks. I find that the best way for students to learn this material is to plan a project (the Christopher Columbus case at the end of this chapter is designed to help in this regard). This material is also intended to help students understand how one prepares a bid in response to a RFB (request for bid) or RFP (request for proposal), and, conversely, how one evaluates submitted bids.

Solutions to Study Problems:

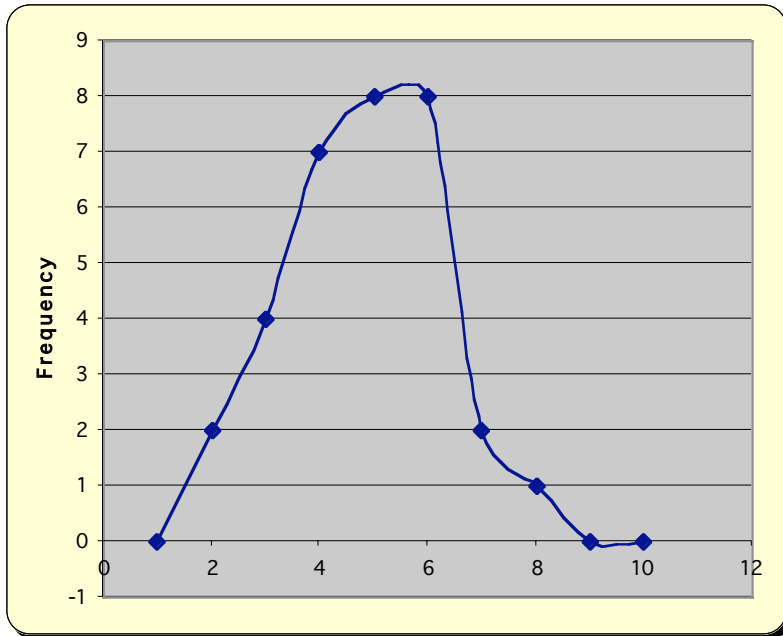
Problem 2.1) No right or wrong answer. Problem designed to motivate discussion on students' previous experience with project selection and initiation methodologies.

Problem 2.6) The time estimates for the painting project were drawn from a beta distribution with mean of 33.0 and a variance of 41.14 (standard deviation of 6.414). The distribution of sample times is given in the following graph along with the fractile estimates requested in the problem.

In the first printing, there is an error in the formula for computing the mean using seven fractiles on the top of page 53. The correct formula should read:

$$\mu = 0.04 (t_{99} + t_{01}) + 0.11 (t_{90} + t_{10}) + 0.23 (t_{75} + t_{25}) + 0.24 t_{50}$$

In the text (first printing), the coefficient for the $(t_{99} + t_{01})$ term in the equation was incorrectly given as 0.4.



The estimates requested in the problem are given below:

PERT estimate:

mean (μ)= 26.30

std dev = 5.33

Three factile estimate:

mean (μ)= 26.28

std dev = 8.62

Five factile estimate:

mean (μ)= 28.05

std dev = 9.61

Seven factile estimate:

mean (μ)= 25.53

std dev = 5.80

The number of hours that a student would bid on the job, of course, depends on how risk averse he/she is....and what incentives/penalties are provided for over- or under-estimating the job.

Problem 2.7

Do we proceed with marketing development now? (Assume cash flows occur at end of year)

Year	Cash flow (product superior)	Cash flow (product inferior)	Expected cash flow	DCF
1	\$ (10.00)	\$ (10.00)	\$ (10.00)	\$ (9.09)
2	\$ (10.00)	\$ -	\$ (6.00)	\$ (4.96)
3	\$ 10.00	\$ -	\$ 6.00	\$ 4.51
4	\$ 10.00	\$ -	\$ 6.00	\$ 4.10
5	\$ 10.00	\$ -	\$ 6.00	\$ 3.73
6	\$ 10.00	\$ -	\$ 6.00	\$ 3.39
7	\$ 10.00	\$ -	\$ 6.00	\$ 3.08
8	\$ 10.00	\$ -	\$ 6.00	\$ 2.80
9	\$ 10.00	\$ -	\$ 6.00	\$ 2.54
10	\$ 10.00	\$ -	\$ 6.00	\$ 2.31
11	\$ 10.00	\$ -	\$ 6.00	\$ 2.10
12	\$ 10.00	\$ -	\$ 6.00	\$ 1.91

prob = 0.60 prob = 0.40

If we proceed now, the expected value of the project is **\$ 16.42**

Based on our assumption that we suspend the project if we learn (in one year) that our competitor has a superior product...

What is we wait for a year to get more information about the competitor's product?

If the company has a better product, then it should restart the Marketing phase; otherwise, it should abandon the project without any further investment.

If the company does have a superior product, however, the product life span is reduced to nine years.

Year	Cash flow (product superior)	Cash flow (product inferior)	Expected cash flow	DCF
1	\$ -		\$ -	\$ -
2	\$ (10.00)	\$ -	\$ (6.00)	\$ (4.96)
3	\$ (10.00)	\$ -	\$ (6.00)	\$ (4.51)
4	\$ 10.00	\$ -	\$ 6.00	\$ 4.10
5	\$ 10.00	\$ -	\$ 6.00	\$ 3.73
6	\$ 10.00	\$ -	\$ 6.00	\$ 3.39
7	\$ 10.00	\$ -	\$ 6.00	\$ 3.08
8	\$ 10.00	\$ -	\$ 6.00	\$ 2.80
9	\$ 10.00	\$ -	\$ 6.00	\$ 2.54
10	\$ 10.00	\$ -	\$ 6.00	\$ 2.31
11	\$ 10.00	\$ -	\$ 6.00	\$ 2.10
12	\$ 10.00	\$ -	\$ 6.00	\$ 1.91

prob = 0.60 prob = 0.40

Expected value of the project is now **\$ 16.49**

Problem 2.8 Part a)

Decision variables are x_j = percent funded of project j ($j = A, B, C, D, E$)

	Decision Variables	Year 1	Year 2	Year 3	Year 4	Year 5
Project A (IT)	0.579	\$40	\$10	\$20	\$20	
Project B	0.614	\$65	\$36	\$30	\$25	\$30
Project C (IT)	1.000	\$6	\$8	\$10		
Project D	0.000	\$20	\$10	\$20	\$20	
Available Funds		\$120	\$40	\$40	\$55	\$60

Cash Flow

	Project Score	Year 1	Year 2	Year 3	Year 4	Year 5	Total Spent
Project A (IT)	0.43	\$ 23.17	\$ 5.79	\$ 11.58	\$ 11.58	\$ -	\$ 52.12
Project B	0.52	\$ 39.90	\$ 22.10	\$ 18.42	\$ 15.35	\$ 18.42	\$ 114.19
Project C (IT)	0.35	\$ 6.00	\$ 8.00	\$ 10.00	\$ -	\$ -	\$ 24.00
Project D	0.00	\$ -	\$ -	\$ -	\$ -	\$ -	\$ -
	1.30	\$ 69.07	\$ 35.89	\$ 40.00	\$ 26.93	\$ 18.42	\$ 190.31

Total Spent on IT projects = \$ 76.12

Total Spent on all projects = \$ 190.31

Proportion spent on IT projects = 40.0%

Part b)

If project D is delayed one year and project C is delayed by two years....

	Decision Variables	Year 1	Year 2	Year 3	Year 4	Year 5
Project A (IT)	0.706	\$40	\$10	\$20	\$20	
Project B	0.329	\$65	\$36	\$30	\$25	\$30
Project C (IT)	1.000			\$6	\$8	\$10
Project D	1.000		\$20	\$10	\$20	\$20
Available Funds		\$120	\$40	\$40	\$55	\$60

Cash Flow

	Project Score	Year 1	Year 2	Year 3	Year 4	Year 5	Total Spent
Project A (IT)	0.523	\$ 28.23	\$ 7.06	\$ 14.12	\$ 14.12	\$ -	\$ 63.52
Project B	0.278	\$ 21.42	\$ 11.86	\$ 9.88	\$ 8.24	\$ 9.88	\$ 61.28
Project C (IT)	0.353	\$ -	\$ -	\$ 6.00	\$ 8.00	\$ 10.00	\$ 24.00
Project D	0.457	\$ -	\$ 20.00	\$ 10.00	\$ 20.00	\$ 20.00	\$ 70.00
	1.61	\$ 49.65	\$ 38.92	\$ 40.00	\$ 50.35	\$ 39.88	\$ 218.80

Total Spent on IT projects = \$ 87.52

Total Spent on all projects = \$ 218.80

Proportion spent on IT projects = 40.0%

Problem 2.9

Projects must be funded at a zero or 100 percent level only....

	1	2	3	4	5	Project Score
Project A (IT)	\$40	\$10	\$20	\$20	-	0.741
Project B	\$65	\$36	\$30	\$25	\$30	0.845
Project C (IT)	\$6	\$8	\$10	-	-	0.353
Project D	\$20	\$10	\$20	\$20	-	0.457
Available Funds	\$120	\$40	\$40	\$55	\$60	

Cash Flow						
Percent funded	1	2	3	4	5	Total Spent
0.00	\$ -	\$ -	\$ -	\$ -		\$ -
1.00	\$ 65.00	\$ 36.00	\$ 30.00	\$ 25.00	\$ 30.00	\$ 186.00
0.00	\$ -	\$ -	\$ -			\$ -
0.00	\$ -	\$ -	\$ -	\$ -		\$ -
0.85	\$ 65.00	\$ 36.00	\$ 30.00	\$ 25.00	\$ 30.00	\$ 186.00

Total spent = \$ 186.00

Total spent on IT projects= \$0

Percent spent on IT projects= **0.0%**

Problem 2.10

If the company proceeds now without waiting a year....

Discount rate = 12%

Year	Event	Cash Flow (Product Development Succeeds)	Cash Flow (Product Development Fails)	Expected Cash Flow	Discounted Cash Flow
1	Product Development	-6	-6	-6	-5.36
2	Product Development	-6	-6	-6	-4.78
3	Product Development	-6	-6	-6	-4.27
4	Product Launch	-4	0	-2.8	-1.78
4	Revenues	9.8	0	6.86	4.36
5	Revenues	9.8	0	6.86	3.89
6	Revenues	9.8	0	6.86	3.48
7	Revenues	9.8	0	6.86	3.10
8	Revenues	9.8	0	6.86	2.77
<i>probability = 0.70</i> <i>probability = 0.30</i>					\$ 1.41

Problem 2.11

The product development phase has succeeded successfully...

Assume that all cash flows occur at the END of the year.....

If Trid does NOT wait to launch new soap powder....

Year	Event	Cash flow (product superior)	Cash flow (product inferior)	Expected Cash flow	Discounted Cash Flow
1	Launch	-4	-4	-4	-3.57
1	Revenues	12	-3	8.25	7.37
2	Revenues	12	0	9	7.17
3	Revenues	12	0	9	6.41
4	Revenues	12	0	9	5.72
5	Revenues	12	0	9	5.11
		<i>prob = 0.75</i>	<i>prob = 0.25</i>		\$ 28.20

If Trid decides to wait one year before possible product launch...

Year	Event	Cash flow (product superior)	Cash flow (product inferior)	Expected Cash flow	Discounted Cash Flow
1	Wait	0	0	0	0.00
2	Launch	-4	0	-3	-2.39
2	Revenues	12	0	9	7.17
3	Revenues	12	0	9	6.41
4	Revenues	12	0	9	5.72
5	Revenues	12	0	9	5.11
		<i>prob = 0.75</i>	<i>prob = 0.25</i>		\$ 22.02

Problem 2.12

Part a: $n = 95$ repetitions to complete a task in 8 minutes or less

Part b: At the end of her first 8-hour shift, she can complete a task at approximately 8.17 minutes. If she starts her next shift at a 95 percent efficiency (meaning that she has had some forgetting between shifts), then it would take her approximately $8.17/0.95 = 8.6$ minutes to complete the first task on her second shift.

Assuming that her learning rate remains constant from the previous day, this would imply that it would take her 4 trials to achieve a goal of 8 minutes or less.

New Problems (not in text):

Problem 2.n

You have taken a project management position with STARCAR Inc., a company is a leader in the development of electric vehicles. You have been negotiating with a major rental car company a fixed-price contract for the development of an electric minivan that they would subsidize over the next six years. The rental car company (the client) has proposed the payment schedule in the following table that also indicates your estimated costs (all monetary numbers are in \$M).

Year	Client	
	payments	Costs
0	\$10	\$7
1	\$8	\$5
2	\$0	\$10
3	\$0	\$8
4	\$0	\$3
5	\$5	\$2
6	\$20	\$1

The STARCAR CFO has suggested that using a discount rate of 15 percent for this project would be appropriate. Discussions with the engineering staff managers reinforce the view that the cost estimates are shaky and could vary as much as 30 percent up and down. Given these estimates, would you recommend that STARCAR accept this contract (that is viewed as important but not essential to the company's long-term success)? What is the probability that this project would show a net profit for STARCAR?

The CFO has suggested that you might use a discount rate of 20 percent in years 5 and 6 due to the increased uncertainty in oil prices, inflation, etc. Would this change your feeling about this project?

Solution to Problem 2.n

Year	Client		Cash Flow	DCF	Random #	Mod Costs	Mod Cash Flow
	payments	Costs					
0	\$10	\$7	\$3	\$3.00	0.61621	\$7.49	\$2.51
1	\$8	\$5	\$3	\$2.61	0.19723	\$4.09	\$3.40
2	\$0	\$10	-\$10	-\$7.56	0.71740	\$11.30	-\$8.55
3	\$0	\$8	-\$8	-\$4.93	0.29675	\$6.59	-\$4.33
4	\$0	\$3	-\$3	-\$1.72	0.84075	\$3.61	-\$2.07
5	\$5	\$2	\$3	\$1.49	0.03764	\$1.45	\$1.77
6	\$20	\$1	\$19	\$8.21	0.70370	\$1.12	\$8.16
				\$1.11	\$0.90		

Run	Mod DCF	Profit?	Mean DCF	Stdev DCF	Prob of profit
1	\$0.90	1	\$0.94	2.31	66.0%
2	\$0.24	1			
3	-\$2.37	0			
4	-\$2.15	0			
5	\$1.76	1			
6	\$2.67	1			
7	-\$0.60	0			
8	\$0.54	1			
9	-\$3.20	0			
10	\$0.83	1			
11	\$2.84	1			
12	-\$0.20	0			
13	\$2.60	1			
14	-\$1.12	0			
15	-\$1.00	0			
16	\$2.18	1			
17	-\$1.88	0			
18	-\$3.61	0			
19	\$3.84	1			
20	\$2.53	1			
21	-\$1.24	0			
22	-\$3.14	0			
23	\$3.63	1			
24	\$0.44	1			
25	\$1.08	1			
26	\$4.78	1			
27	\$0.79	1			
28	\$3.80	1			
29	\$1.45	1			
30	\$3.75	1			
31	-\$0.84	0			
32	\$2.80	1			
33	\$4.17	1			
34	-\$1.04	0			
35	\$2.78	1			
36	-\$1.87	0			
37	\$0.95	1			
38	\$3.82	1			
39	\$4.82	1			
40	-\$0.14	0			
41	\$5.09	1			
42	-\$1.69	0			
43	\$0.61	1			
44	\$1.73	1			
45	-\$2.21	0			
46	\$3.03	1			
47	\$3.19	1			
48	\$0.64	1			
49	\$0.71	1			
50	\$0.58	1			

Problem 2.n+1:

Starbucks Debit Card

As described in the article by Fichman et al. "Beyond Valuation: "Options Thinkiing" in IT Project Management", Starbucks introduction of their pre-paid debit card was broken into several stages in order to minimize the risks associated with the project. Specifically, the four stages were as follows:

- Stage 1: Install basic hardware and software at local store level to support simple debit card
Stage 2: Install on-line registration of cards to allow users to replace lost cards, reload cares with additional money, etc.
Stage 3: Install loyalty points program, including email notification system
Stage 4: Introduce co-branded Visa card with Bank One

It was estimated that each stage would take two years to implement; the cost per year and the potential gain at the end of two years from successful implementation are indicated in the table below (in \$M). The conditional probability of each stage's success, given that the previous stage is successful, is also indicated in the table. If a stage fails, it is assumed that there is no gain at the end of the two year implementation period. The stages must be done in sequence if implemented (for example, you could not choose to implement stages 1, 3, and 4).

Stage	Annual Implementation Costs	Estimated gain from successful implementation	Prob of success
1	(\$5.00)	\$14	0.8
2	(\$2.35)	\$5.50	0.65
3	(\$1.15)	\$3.50	0.5
4	(\$0.85)	\$1	0.65

Starbucks used a discount rate of 15 percent for this project. If you were the project manager assigned to this project, would you have recommended that Starbucks' proceed as planned or modify the plan (and if so, how)?

Problem 2.n+2:

Howtronics Corporation has recently developed a new graphics display unit that may provide the same quality as plasma screens but at a fraction of the cost. The management of Howtronics is trying to decide whether they should produce the units themselves or subcontract their production to an OEM. Management feels that the key criteria on this decision is the market response to the new screen; if the demand is high, it would be worthwhile to invest in the equipment and skilled workforce to build the screens themselves. However, if demand is low, then they would prefer to outsource the production of the screen.

You have been assigned the job of determining what Howtronics should do. After considerable study and discussions with your ex-UW professors, you have arrived at the following estimates of discounted costs (in thousands of dollars) and likelihood estimates of each scenario.

	Future Demand for New Product		
	<i>Low</i>	<i>Average</i>	<i>High</i>
Produce In-House	\$140	\$120	\$90
Outsource	\$100	\$110	\$160
Probability	0.1	0.6	0.3

- a) Based on your cost and probability estimates, would you recommend that Howtronics build the new product in-house or outsource its production to an OEM?
- b) Assuming the probability of low demand remains constant (at 0.10), what values must the probabilities of average and high demand take in order for you to be indifferent between in-house production and outsourcing?
- c) What other factors should you consider when considering this decision?

Solution to Problem 2.n+2:

Solutions:

a)

	Future Demand for New Product			Expected Cost
	<i>Low</i>	<i>Average</i>	<i>High</i>	
Produce In-House	\$140	\$120	\$90	\$113.00
Outsource	\$100	\$110	\$160	\$124.00
Probability	0.1	0.6	0.3	

b)

Let x = probability that demand will be average (so $.9-x$ = prob that demand is high)

$$140 (.1) + 120 x + 90 (.9-x) = 100 (.1) + 110 x + 160 (.9-x)$$

$$\text{Thus, } x = 0.7375$$

c)

Some other factors include lower risk (variance); producing in-house will define core competency for company that may have impact on other projects;

Teaching Note on **Christopher Columbus, Inc.**



I use this case to illustrate and discuss the following issues:

- 1) Project planning and bid preparation
- 2) The relationship between goals and project definition.
- 3) Defining metrics for project assessment
- 4) How to prepare a risk mitigation plans
- 5) Evaluating submitted bids

Each study group is asked to prepare a project proposal and present their proposal and bid to the king and queen; each presentation must be less than 10 minutes (depending on the number of study teams). Placing a time limit requires gives students the experience of presenting a great deal of material in a succinct and concise manner.

One of the key issues in this case is the identification of specific goals and relating these goals to the definition of tasks and activities. This case is also designed to illustrate that frequently goals may conflict with each other. For example, since the RFP in the case states that certain factors are important to the king and queen (e.g., identifying trade routes to Asia), many students state that an important goal is to bring back gold and spices to pay for their project and reward the sponsors of the project. This is very different from a project whose primary goal is knowledge acquisition (e.g., find out if there is a trade route to Asia that can be accessed by sailing west). In the former case (i.e., bring back lots of stuff), the number and size of ships that return are important. In the latter case (i.e., gain knowledge), only one sailor floating on a log needs to return to have a successful project. So the definition of goals impacts the way that the project outcome will be assessed, the cost of the project (e.g., which ships should be purchased), and project duration.

Another key issue concerning goal identification is how these goals will be measured. Many students indicate that a primary goal is to “Spread Christianity” as indicated in the case. However, they fail to define any metrics for measuring and assessing this goal. It

is important to emphasize that metrics must be identified for each goal and criteria must be established which will indicate the success or failure of the project.

A key part of this case is the determination of which boats to purchase. Again, this relates to the goals selected by each study team. The case states that three boats will be purchased for the voyage but the choice of boats will differ greatly depending on the project's defined goals. For example, if knowledge acquisition is the key goal, then the boats might be selected to maximize the probability that at least one boat returns safely. If a primary goal is the acquisition of gold and spices, then students might want to maximize the probability that all three boats return safely. I also use the boat selection process to introduce a discussion on the concept of efficient frontiers; that is, why would you consider a boat that has the same likelihood of survival as another boat but has a greater cost?

With respect to bid preparation, I also use this case to emphasize the relationship between the definition of milestones and the payment schedule. Does the study group expect all payments up front or will some payments be made at the successful conclusion of certain milestones? If so, what are these milestones?

Another key aspect of this case is the introduction of risk assessment and mitigation. Each team is required to present their list of risks and managing these risks (e.g., sailors will fish on the voyage to minimize the cost of food and reduce the likelihood of starvation).

As bids are presented by study groups, I write key information about each bid on the board (e.g., expected project duration, costs, boats selected, etc). At the end of the presentations, I ask how the king and queen should evaluate these bids given that there is typically a great deal of variation in costs and durations among the bids. I use this discussion to introduce concepts relating to quality assurance and control, including the use of pre-qualification lists in projects.

Chapter 3: Project Teams and Organizational Relationships

This chapter introduces issues relating to the formation and management of project teams as well as organizational issues. I usually spend one class on the material in this chapter, emphasizing the role of a project manager and the importance of effective communication with all project stakeholders. I also discuss in some detail the results of the Brown *et al.* study that indicated that some degree of contentiousness among project members may be a healthy attribute for a project team (this usually results in a fairly animated class discussion). I also discuss the issues of organizational structure raised by the Larson and Gobeli study and the need to give project managers a significant responsibility for project matters.

Another topic of importance in this chapter is the relationship between clients and contractors and the need to view this relationship as a partnership and business alliance—not merely as a boss-worker relationship.

Notes on Study Problems:

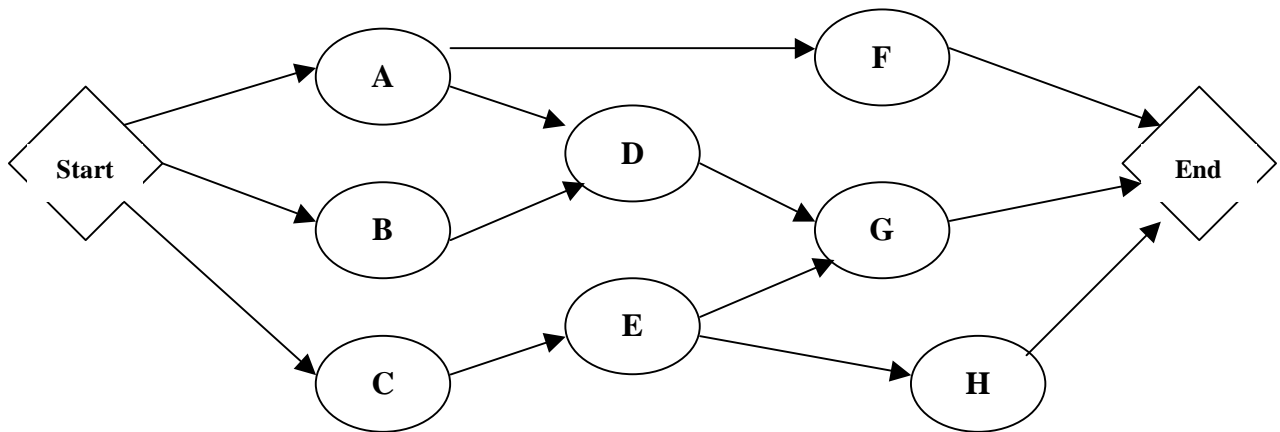
These study problems are repeated from Chapter 1. In the first chapter (without any background), the problems were intended to motivate and stimulate students' thinking about issues relating to the formation of project teams, matrix organizations, and other organizational issues. Having discussed project planning (in the second chapter) and behavioral/organizational issues (in the third chapter), these problems are repeated to give students a chance to see how their thinking has (hopefully) evolved as the course has progressed. In addition, student responses should now be phrased in context of the material presented in the third chapter.

Chapter 4: Precedence Networks and the Critical Path Method (CPM)

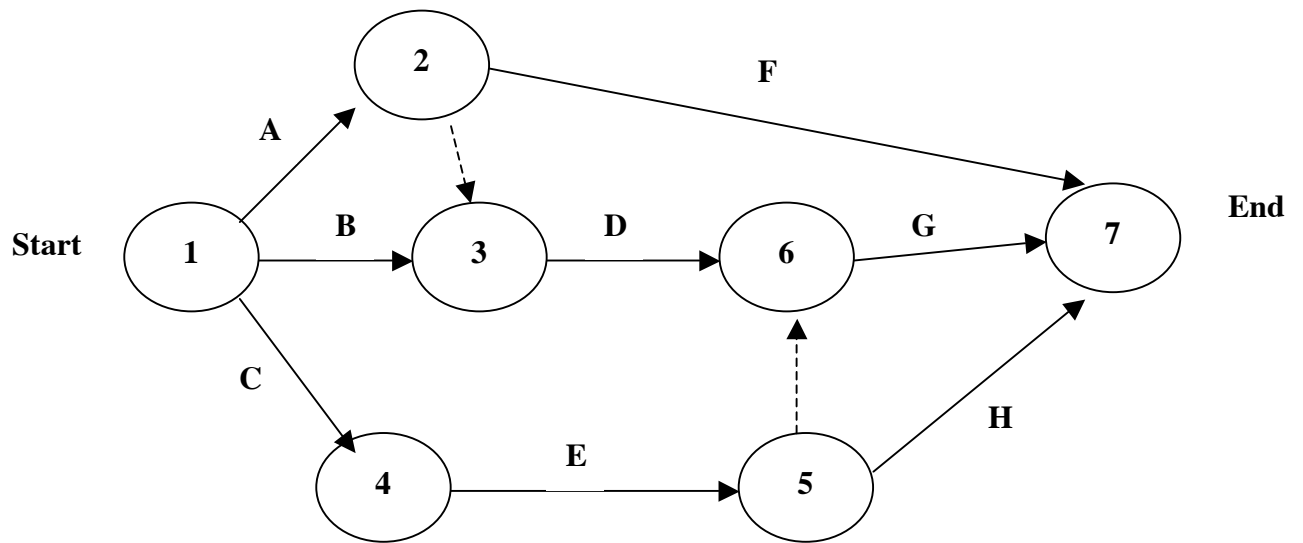
This chapter describes the basics of constructing both AON (Activity-on-Node) and AOA (Activity on Arc) precedence networks, the calculations of the critical path method, and the concepts of various definitions of slack. This is the “nuts and bolts” behind most PM software. The chapter also shows how linear programming (via Solver in Excel spreadsheets) can be used to find the minimum project makespan. The linear programming models are important as they are extended in future chapters to deal with more realistic trade-offs faced by most project managers (cash flow, schedule compression, etc).

Solutions to Study Problems:

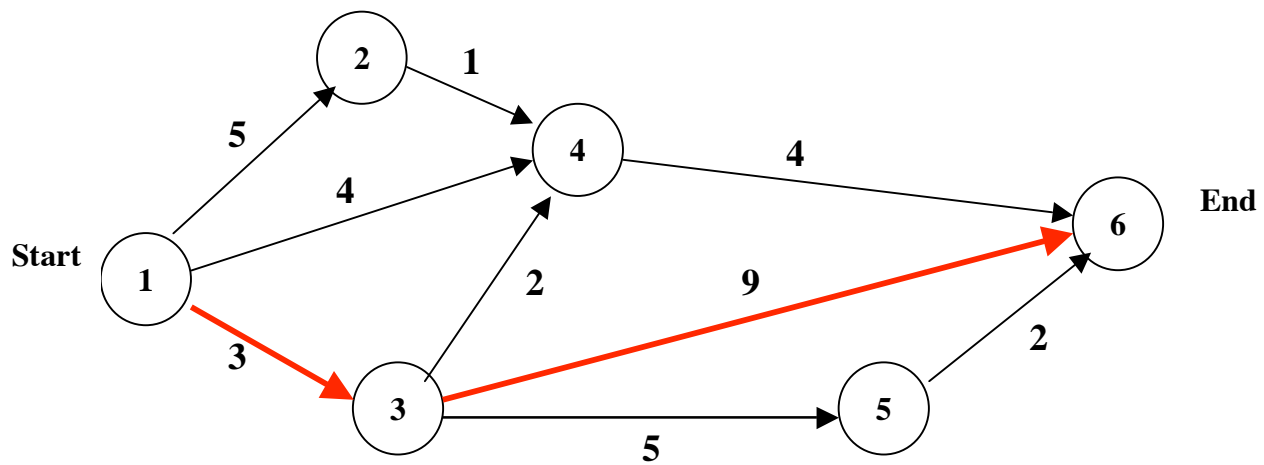
Problem 4.1 The AON network:



The AOA network:

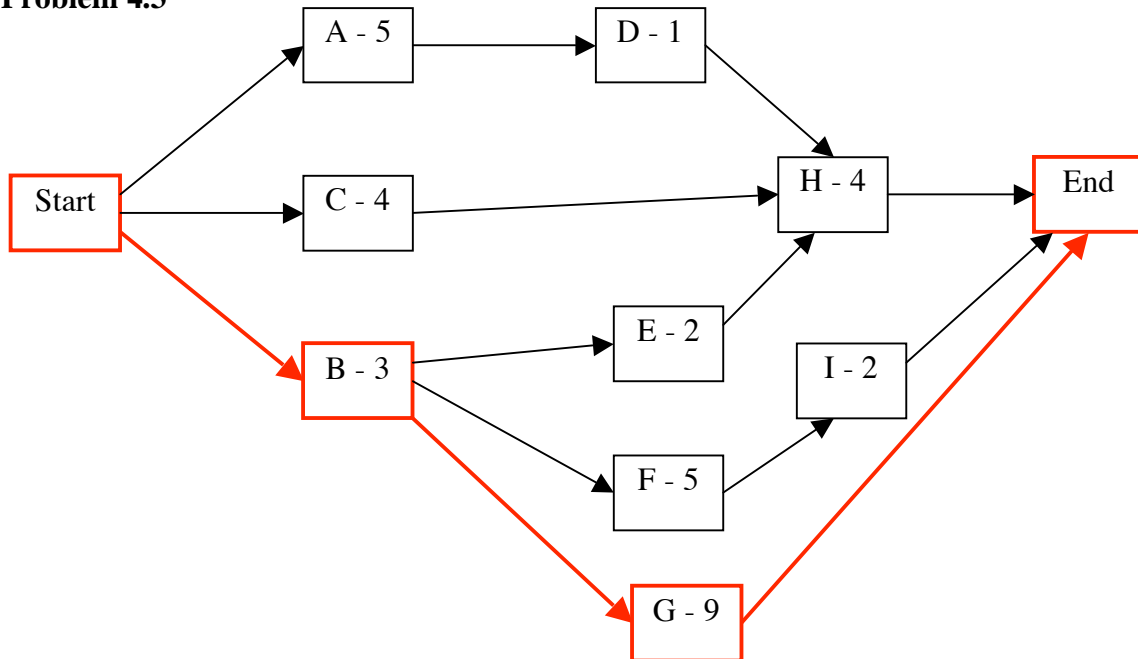


Problem 4.2



		E A R L Y		L A T E					
Task	Duration	Start	Finish	Start	Finish	Total Slack	Free Slack	Safety Slack	Independent Slack
(1, 2)	5	0	5	2	7	2	0	2	0
(1, 3)	3	0	3	0	3	0	0	0	0
(1, 4)	4	0	4	4	8	4	2	4	2
(3, 4)	2	3	5	6	8	3	1	3	1
(3, 5)	5	3	8	5	10	2	0	2	0
(3, 6)	9	3	12	3	12	0	0	0	0
(4, 6)	4	6	10	8	12	2	2	0	0
(2, 4)	1	5	6	7	8	2	0	0	0
(5, 6)	2	8	10	10	12	2	2	0	0

Problem 4.3



		E A R L Y		L A T E					
Task	Duration	Start	Finish	Start	Finish	Total Slack	Free Slack	Safety Slack	Independent Slack
Start	0	0	0	0	0	0	0	0	0
A	5	0	5	2	7	2	0	2	0
B	3	0	3	0	3	0	0	0	0
C	4	0	4	4	8	4	2	4	2
D	1	5	6	7	8	2	0	0	0
E	2	3	5	6	8	3	1	3	1
F	5	3	8	5	10	2	0	2	0
G	9	3	12	3	12	0	0	0	0
H	4	6	10	8	12	2	2	0	0
I	2	8	10	10	12	2	2	0	0
End	0	12	12	12	12	0	0	0	0

In the first printing, there is an error in problem 4 on page 101. The phrase in line 3 of the problem “and the critical path, and safety slack (float) values.” should be omitted. As presently stated, problems 4 and 5 are basically identical.

Problem 4.4


	A	B	C	D	E	F	G	H
1								
2								
3	<i>Decision variables:</i> STARTj = starting time of task j							
4	END = time that project ends							
5								

Task	Starting Times		Task Durations	Finish Times	
	Variables	Values		Variables	Values
Start	Start	0	0		
A	STARTA	0	5	FINISHA	5
B	STARTB	0	3	FINISHB	3
C	STARTC	0	4	FINISHC	4
D	STARTD	5	1	FINISHD	6
E	STARTE	3	2	FINISHE	5
F	STARTF	3	5	FINISHF	8
G	STARTG	3	9	FINISHG	12
H	STARTH	6	4	FINISHH	10
I	STARTI	8	2	FINISHI	10
End	END	12	0		


Minimize project duration (early start times) =

40

Solver Parameters

Set Target Cell: 

Equal To: ☐ Max ☒ Min ☐ Value of:

By Changing Cells: 

Subject to the Constraints:

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Buttons: Solve, Close, Options, Add, Change, Delete, Reset All, Help

Problem 4.5


	A	B	C	D	E	F	G	H
1								
2								
3	<i>Decision variables:</i> START _j = starting time of task j							
4	END = time that project ends							
5								

Task	Starting Times		Task Durations	Finish Times	
	Variables	Values		Variables	Values
Start	Start	0	0		
A	STARTA	2	5	FINISHA	7
B	STARTB	0	3	FINISHB	3
C	STARTC	4	4	FINISHC	8
D	STARTD	7	1	FINISHD	8
E	STARTE	6	2	FINISHE	8
F	STARTF	5	5	FINISHF	10
G	STARTG	3	9	FINISHG	12
H	STARTH	8	4	FINISHH	12
I	STARTI	10	2	FINISHI	12
End	END	12	0		


Minimize project duration latest start times) =

1143

Solver Parameters

Set Target Cell: 

Equal To: ☐ Max ☒ Min ☐ Value of:

By Changing Cells: 

Subject to the Constraints:

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- Problem 4.6** a) What is the duration of task (1,3)? **Duration of (1,3) = 10**
b) What is the duration of task (2,3)? **Duration of (2,3) = 2**
c) What is the total slack of task (3,4)? **Total slack = 0 (critical task)**
d) What is the safety slack of task (4,5)? **Safety slack = 0 (critical task)**
e) What is the free slack of task (2,5)? **Free slack = 27 - 6 - 12 = 9**
f) What is the independent slack of task (2,4)? **Ind slack = max (0, 18-8-7) = 3**

Problem 4.7 a) Does Independent Slack = min (Free Slack, Safety Slack)?

The conjecture is true; proof is based on the definition of slacks.

b) Total Slack + Free Slack = Safety Slack + Independent Slack ?

This conjecture does not hold....

Ignore the fact that $T_j^E - T_i^L - t_{ij}$ could be less than zero.

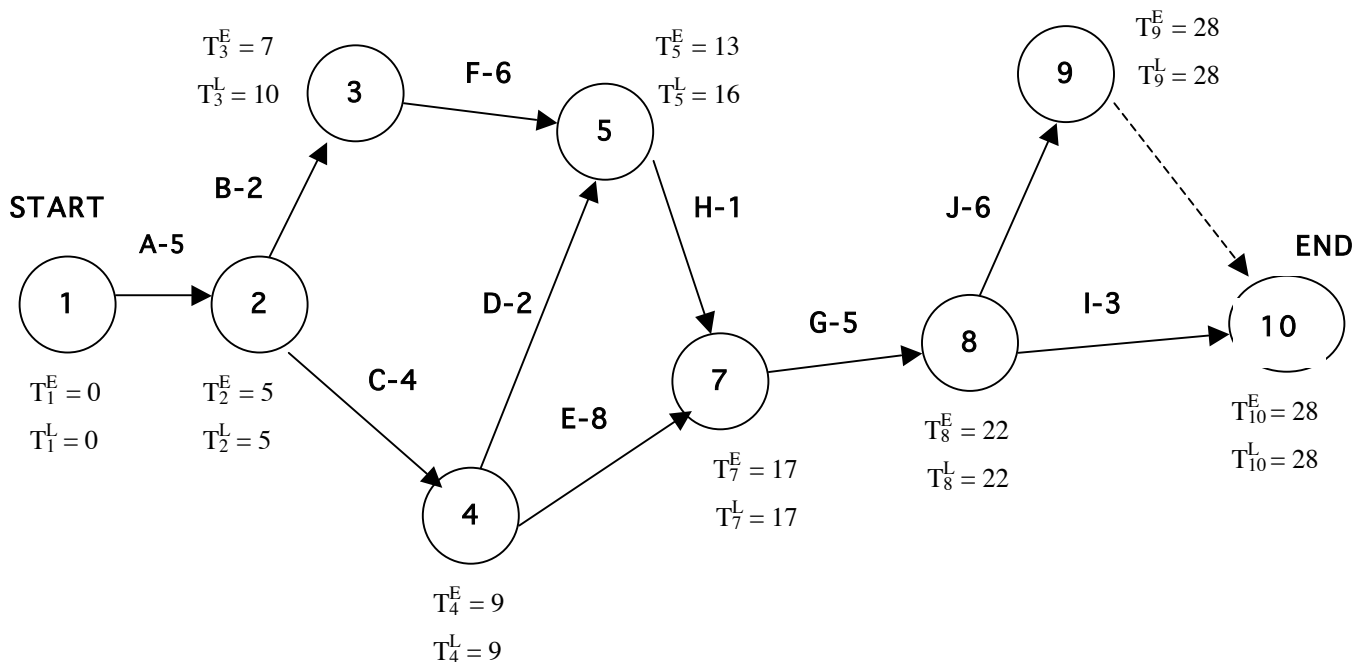
Then, by definition (for AOA networks):

$$(T_j^L - T_i^E - t_{ij}) + (T_j^E - T_i^E - t_{ij}) = (T_j^L - T_i^L - t_{ij}) + (T_j^E - T_i^L - t_{ij})$$

$$\text{Total slack} + \text{Free Slack} = \text{Safety Slack} + \text{Independent Slack}$$

Simplifying we find that $T_i^E = T_i^L$ that may not hold. Hence, the hypothesized relationship may not hold.

Problem 4.8



a)

Task (i,j)	t_{ij}	T_i^E	T_j^L	TS_{ij}	Critical?	FS_{ij}	SS_{ij}	IS_{ij}
(1,2)	5	0	5	0	yes	0	0	0
(2,3)	2	5	10	3	no	0	3	0
(2,4)	4	5	9	0	yes	0	0	0
(3,5)	6	7	16	3	no	0	0	0
(4,5)	2	9	16	5	no	2	5	2
(4,7)	8	9	17	0	yes	0	0	0
(5,7)	1	13	17	3	no	3	0	0
(7,8)	5	17	22	0	yes	0	0	0
(8,9)	6	22	28	0	yes	0	0	0
(8,10)	3	22	28	3	no	3	3	3
(9,10)	0	28	28	0	yes	0	0	0

b)

Decision variables: x_j = occurrence time of event j

C O N S T R A I N T S												
Variables	Values	$x_2 - x_1 \geq t_{12}$	$x_3 - x_2 \geq t_{23}$	$x_4 - x_2 \geq t_{24}$	$x_5 - x_3 \geq t_{35}$	$x_5 - x_4 \geq t_{45}$	$x_7 - x_4 \geq t_{47}$	$x_7 - x_5 \geq t_{57}$	$x_8 - x_7 \geq t_{78}$	$x_9 - x_8 \geq t_{89}$	$x_{10} - x_8 \geq t_{8,10}$	$x_{10} - x_9 \geq t_{9,10}$
x_1	0	0.00										
x_2	5	5.00	-5.00	-5.00								
x_3	7		7.00		-7.00							
x_4	9			9.00		-9.00	-9.00					
x_5	13				13.00	13.00		-13.00				
x_7	17						17.00	17.00	-17.00			
x_8	22								22.00	-22.00	-22.00	
x_9	28								28.00	28.00		-28.00
x_{10}	28										28.00	28.00
$x_j - x_i$		5.00	2.00	4.00	6.00	4.00	8.00	4.00	5.00	6.00	6.00	0.00
t_{ij}		5	2	4	6	2	8	1	5	6	3	0
$x_j - x_i - t_{ij}$		0	0	0	0	2	0	3	0	0	3	0

Minimize $(x_{10} - x_1) =$ 28

Minimize $(x_{10} + x_9 + x_8 + x_7 + x_6 + x_5 + x_4 + x_3 + x_2 - x_1) =$ 129 earliest occurrence times

Minimize $(10x_{10} - x_9 - x_8 - x_7 - x_6 - x_5 - x_4 - x_3 - x_2 - x_1) =$ 179 latest occurrence times

Task (i,j)	t_{ij}	T_i^E	T_j^L	TS_{ij}	Critical?	FS_{ij}	SS_{ij}	IS_{ij}
(1,2)	5	0	5	0	yes	0	0	0
(2,3)	2	5	10	3	no	0	3	0
(2,4)	4	5	9	0	yes	0	0	0
(3,5)	6	7	16	3	no	0	0	0
(4,5)	2	9	16	5	no	2	5	2
(4,7)	8	9	17	0	yes	0	0	0
(5,7)	1	13	17	3	no	3	0	0
(7,8)	5	17	22	0	yes	0	0	0
(8,9)	6	22	28	0	yes	0	0	0
(8,10)	3	22	28	3	no	3	3	3
(9,10)	0	28	28	0	yes	0	0	0

Solver Parameters

Set Target Cell: $\$F\24

Equal To: ☐ Max ☒ Min ☐ Value of: 0

By Changing Cells: $\$B\$9:\$B\16

Subject to the Constraints:

$\$B\$9:\$B\$16 \geq 0$

$\$C\$19:\$M\$19 \geq 0$

Buttons: Solve, Close, Options, Reset All, Help

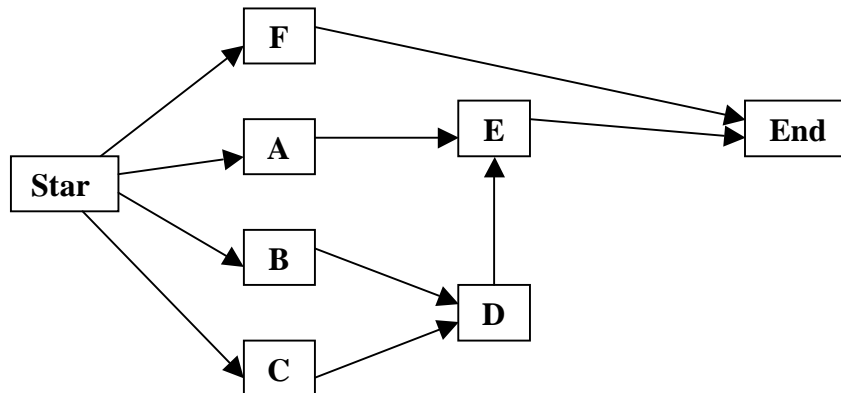
- c) i) early start time of task D is not a function of the duration of task D
 ii) by more than 5 days
 iii) by more than 5 days
- d) If task C is a predecessor of task F, then
 i) Early start time of task F will change by 2 days;
 early start time of task H will change by 2 days
 ii) No tasks will have their latest start times changed

Problem 4.9 The data table in this problem is incorrect (same as the data table in problem 4.8)....the correct data table should be:

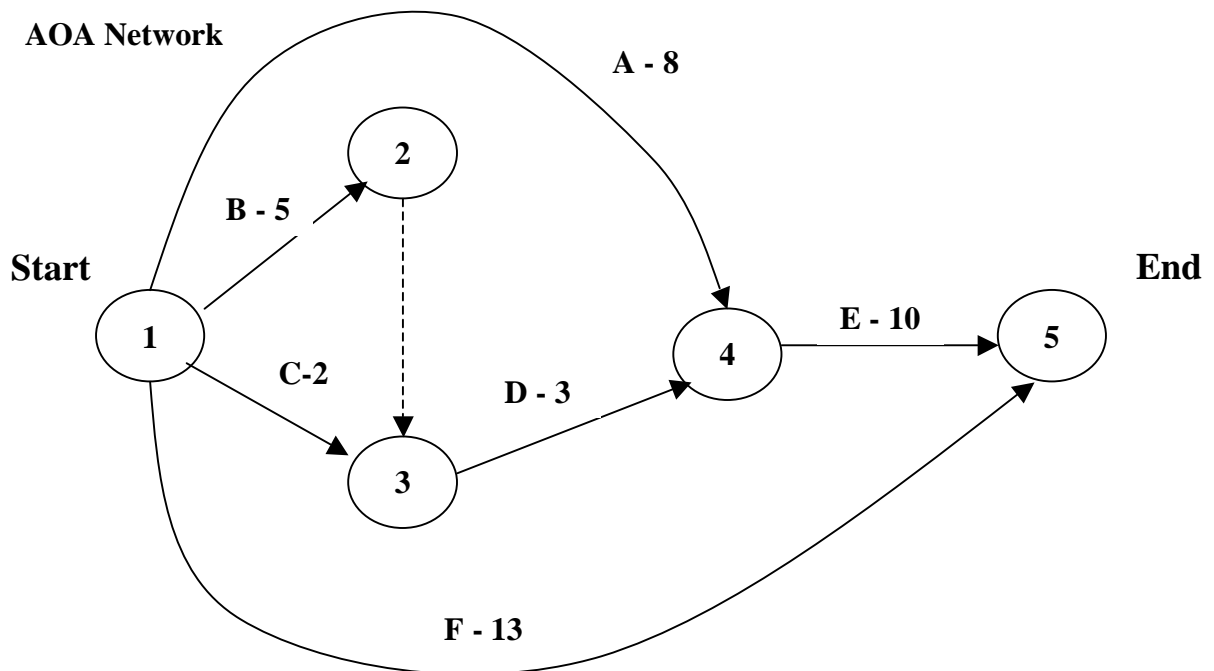
Task ID	Immediate Predecessor(s)	Duration
A	-	8
B	-	5
C	-	2
D	B,C	3
E	A,D	10
F	-	13

Solutions:

a. AON network



AOA Network

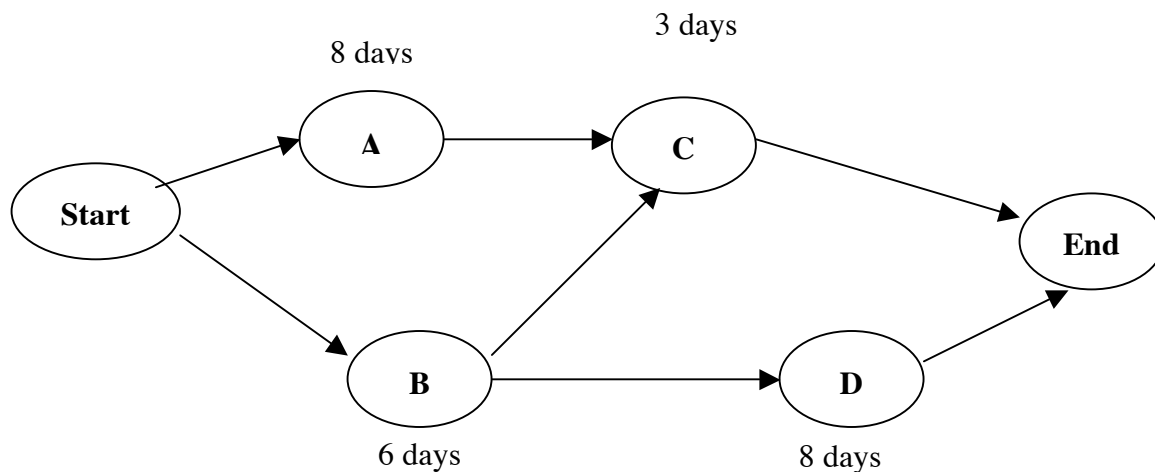


b) Using the AON network:

Task	Duration	E A R L Y Start	Finish	L A T E Start	Finish	Total Slack	Free Slack	Safety Slack	Independent Slack
A	8	0	8	0	8	0	0	0	0
B	5	0	5	0	5	0	0	0	0
C	2	0	2	3	5	3	3	3	3
D	3	5	8	5	8	0	0	0	0
E	10	8	18	8	18	0	0	0	0
F	13	0	13	5	18	5	5	5	5

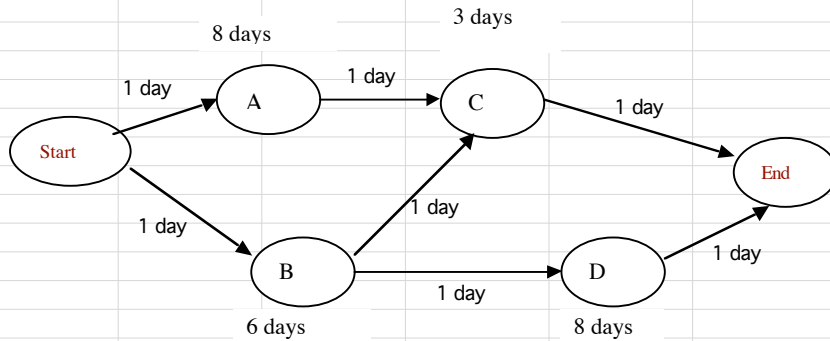
Problem B1 (p. 106) The problem should read as follows (error in the first printing):

B1. Use the following AON precedence network (and given task durations) to find the slack values in parts (a) and (b).



- Assuming that tasks A, B, C, and D follow a Finish-to-Start relationship with a lag of 1 day, find the total slack for tasks A, B, C, and D.
- Assuming that tasks A, B, C, and D follow a “Start-to-Start” relationship with zero lag, find the total slack for tasks A, B, C, and D.

Solution to Problem B1:



a) If we assume that one day lag is added to EVERY arc, the project makespan increases to 17 days (the critical path is START-B-D-END). The total slacks in this case are:

Task	Total Slack
A	3
B	0
C	3
D	0

b) If we use a Start-to-start relationship, then all tasks can effectively start at time zero. The total slacks then are:

Task	Total Slack
A	0
B	2
C	5
D	0

Teaching Note: some students will not add a lag to the precedence relationships between START and tasks A and B, or to the arcs between tasks C and D, and END. In either case, this does not change the slack values.

Chapter 5: Planning to Minimize Costs

On page 118, paragraph 5, there is an error with the equation for the total direct cost of the project. The material (through the top of page 119) should read

For any j^{th} task, the direct cost can be found knowing the value of t_j . From Figure 5.10, the direct cost associated with task duration t_j is

$$C_j^N + b_j(t_j - t_j^N) = C_j^N + b_j t_j - b_j t_j^N$$

where $b_j \leq 0$. Thus, the total direct cost for the project is

$$\sum_j b_j t_j + \sum_j (C_j^N - b_j t_j^N).$$

Since the second term in this cost function is a constant, minimizing $(\sum b_j t_j)$ is equivalent to minimizing total direct costs. The modified linear programming problem to find task starting times and task durations that will minimize total direct costs for a given project duration, T_{\max} , can then be stated as

$$\text{Minimize } \sum_j b_j t_j$$

subject to:

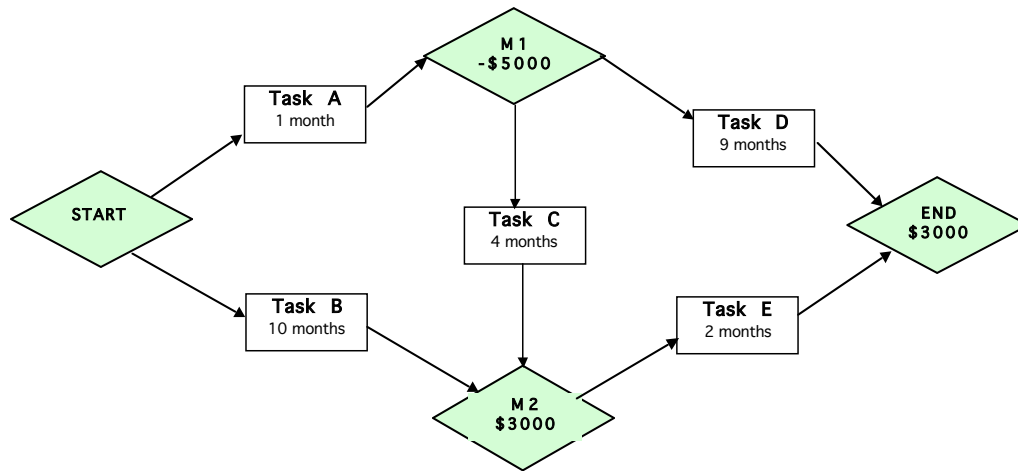
$$\begin{aligned} t_j^c &\leq t_j \leq t_j^N && \text{for all tasks } j \text{ in project} \\ s_j &\geq s_i + t_i && \text{for all tasks } i \text{ in the set } P_j \end{aligned}$$

$$\text{END} = T_{\max}$$

$$s_i \geq 0 \quad \text{for all tasks } i.$$

Solutions to Study Problems:

Problem 5.1: Walla Walla Boat Co.



Decision variables:

START_j = starting times for task j

END = project end time

TASK (or MILESTONE)	Start Times	Duration	Finish Times	Cash Flow	Dollar-Months	NPV
START	0	0	0	\$ -		
Task A	0	1	1			
Task B	0	10	10			
M1	6	0	6	\$ (5,000)	\$ (30,000)	\$ (4,528)
Task C	6	4	10			
M2	10	0	10	\$ 3,000	\$ 30,000	\$ 2,543
Task D	6	9	15			
Task E	10	2	12			
END	15	0	15	\$ 3,000	\$ 45,000	\$ 2,341
					\$ 45,000	\$ 356

Annual discount rate =	2.0%
Monthly discount rate =	1.67%

- a) Project makespan is equal to 12 months
- b) If min dollar-months, project makespan is 15 months
- c) If max NPV project makespan is 15 months

Problem 5.2: Walla Walla Boat Co. (cont'd)

- a) If the payment at milestone M1 is reduced to less than \$3000, the project makespan that maximizes NPV is 12 months
- b) Increasing the payments at milestone M2 (and reducing the payments at the end of the project) only increases the project makespan but will never reduce it

Problem 5.3

Task	Duration	ES_i	LF_i	LS_i
1	3	0	3	0
2	2	3	9	7
3	3	3	6	3
4	3	3	8	5
5	3	6	9	6
6	1	6	9	8
7	1	9	10	9

To minimize holding costs (since the cost of holding the completed task is greater than the cost of holding raw materials), start all tasks at their latest starting times (LS_i); order costs are constant at \$3200 and the holding cost of completed tasks is also constant at \$530

Task	Time (LS_i)	Demand (# units)
3	3	10
4	5	10
5	6	12

Options:

- 1) Order 32 units at time = 3
Cost = $45 + 10(2)(2) + 12(3)(2) = \157
- 2) Order 20 units at time = 3; 12 units at time = 6
Cost = $45(2) + 10(2)(2) = \$130$
- 3) Order 10 units at time = 3; 10 units at time = 5; 12 units at time = 6
Cost = $45(3) = \$135$
- *4) Order 10 units at time = 3; 22 units at time = 5
Cost = $45(2) + 12(1)(2) = \$114$ (optimal policy)

Problem 5.4

Task	N O R M A L		C R A S H		Slope
	Duration	Cost	Duration	Cost	
A	0	0	0	0	-
B	10	100	9	110	10.0
C	8	80	7	100	20.0
D	12	120	10	140	10.0
E	10	100	7	120	6.7
F	14	140	12	190	25.0
G	7	70	5	100	15.0
H	9	90	6	150	20.0
I	6	60	5	80	20.0
		760		990	
<u>Critical Path</u>	<u>Project Makespan</u>		<u>Direct Cost</u>		
A-C-F-H-I-J	37 days		\$760		
Reduce I to 5 days (crash limit)	36 days		\$780		
A-C-F-H-I-J					
Reduce H to 8 days	35 days		\$800		
A-C-F-H-I-J					
Reduce H to 7 days	34 days		\$820		
A-B-D-G-I					
A-C-F-H-I					
Reduce H to 6 days (crash limit)	33 days		\$850		
Reduce B to 9 days					

Problem 5.5

Parts a and b)

PROJECT DURATION	CRITICAL PATH	TASK(S) TO REDUCE	DIRECT COST	OVERHEAD COSTS	TOTAL COSTS
22	START-B-C-END	-	\$610	\$1,100	\$1,710
21	START-B-C-END	REDUCE B TO 9	630	1050	1680
20	START-B-C-END	REDUCE B TO 8	650	1000	1650*
	START-A-C-END				
19	START-B-C-END	REDUCE C TO 11	710	950	1660
	START-A-C-END				
18	START-B-C-END	REDUCE C TO 10	770	900	1670
	START-A-C-END				
17	START-B-C-END	REDUCE C TO 9	830	850	1680
	START-A-C-END				
	START-A-D-E-END				
16	START-B-C-END	REDUCE A TO 7;	900	750	1700
	START-A-C-END	B TO 7			
	START-A-D-E-END				
15	START-B-C-END	REDUCE A TO 6;	970	750	1720
	START-A-C-END	B TO 6			
	START-A-D-E-END				
14	START-B-C-END	REDUCE C TO 8	1055	700	1755
	START-A-C-END	E TO 4			
	START-A-D-E-END				

Part c)

Task	Duration	Starting Time	Finish Time	N O R M A L		C R A S H		Slope	Direct Cost
				Duration	Cost	Duration	Cost		
START	0	0.0	0.0	0	-	0	-	-	-
A	8	0.0	8.0	8	\$100	6	\$200	50	\$100.00
B	8	0.0	8.0	10	\$70	5	\$170	20	\$110.00
C	12	8.0	20.0	12	\$260	8	\$500	60	\$260.00
D	4	8.0	12.0	4	\$80	4	\$80	-	\$80.00
E	5	15.0	20.0	5	\$100	2	\$175	25	\$100.00
END	0	20.0	20.0	0	-	0	-	-	-

Direct cost of performing all tasks = \$650.00
 Project makespan = 20.00
 Overhead/indirect charges/day = \$50
 Indirect/overhead charges for project = \$1,000
 Total project cost = \$1,650.00

Part d) Since the total project cost at 19 days is \$1660 and the minimum cost (at 20 days) is \$1650, there would have to be at least a \$10 bonus offered to make it worthwhile to compress this project to 19 days.

Problem 5.6

- a) If we want to compress the project from the normal duration of 28 weeks to 25 weeks at the smallest possible increase in direct costs:

Duration	Critical Path(s)	Crashed Tasks	Direct Cost Increase
28	START-A-E-F-G-END	-	-
27	START-A-E-F-G-END START-B-C-G-END	F (from 5 to 4)	\$5
26	START-A-E-F-G-END START-B-C-G-END	G (from 10 to 9) F (stays at 4)	\$15
25	START-A-E-F-G-END START-B-C-G-END	G (from 9 to 8) F (stays at 4)	\$25

- b) Solution that minimizes total cost (defined by direct costs, penalty costs, and earliness bonus) is:

Decision variables: t_j = Duration of task j

S_j = Starting time of task j

Starting Times (S_j)		Duration (t_j)		Normal Duration	Crash Duration	Slope (bj)	Cost to Crash
Variables	Values	Variables	Values				
SSTART	0	tSTART	0	0	0	-	-
SA	0	tA	7	7	5	\$ 7	\$ -
SB	0	tB	10	10	8	\$ 10	\$ -
SC	10	tC	7	7	5	\$ 7	\$ -
SD	9	tD	8	8	6	\$ 8	\$ -
SE	7	tE	6	6	4	\$ 6	\$ -
SF	13	tF	4	5	3	\$ 5	\$ 5
SG	17	tG	10	10	8	\$ 10	\$ -
SH	16	tH	11	11	9	\$ 11	\$ -
SEND	27	tEND	0	0	0	-	-

Chapter 6: Planning with Uncertainty

Solutions to Study Problems:

Problem 6.1

Activity	Optimistic time	Most likely time	Pessimistic time	Expected duration	Variance
(1,2)	8	9	10	9.00	0.11
(1,3)	6	7	9	7.17	0.25
(2,6)	9	12	15	12.00	1.00
(3,4)	5	5	5	5.00	0.00
(3,5)	8	10	11	9.83	0.25
(3,6)	11	15	20	15.17	2.25
(4,5)	3	4	6	4.17	0.25
(5,6)	5	6	8	6.17	0.25
(5,7)	8	10	12	10.00	0.44
(6,7)	4	5	10	5.67	1.00

Event	Expected Occurrence	Early Time	Variance	Orig. Schedule	Z score	Probability
1	0		0	0	-	-
2	9		0.11	9	0.00	0.50
3	7.16		0.25	8	1.43	0.92
4	12.16		0.25	12	-0.32	0.63
5	17		0.5	18	1.41	0.92
6	23.17		0.75	25	-1.51	0.93
7	28.83		1.75	30	0.88	0.81

Problem 6.2

Part a) In this case, we use the longest expected path following the basic idea behind the Classic PERT model). The longest expected path in this case is Task (1, 2) – Task (2,4) that has an expected duration of 10.40 days (see table below for calculations). The variance associated with this path is the sum of the variances of Task (1,2) and Task (2, 4) which is $0.64 + 0.96 = 1.60$ (standard deviation is then 1.265).

Task	Days	Prob	Expected duration	Variance
Task (1,2)	2	0.6	2.6	0.64
	3	0.2		
	4	0.2		
Task (1,3)	1	0.1	3.7	0.81
	4	0.9		
Task (2,4)	7	0.6	7.8	0.96
	9	0.4		
Task (3,4)	10	0.5	6	16
	2	0.5		

Classic PERT Model is built on longest expected path: Task (1,2) - Task (2,4)

Realization	Task (1,2)	Task (2,4)	Prob	Project Duration	Expected duration
1	2	7	0.36	9	3.24
3	3	9	0.08	12	0.96
2	4	7	0.12	11	1.32
5	2	9	0.24	11	2.64
4	3	7	0.12	10	1.2
6	4	9	0.08	13	1.04
					10.40

Combining these 6 realizations, we get the following distribution for the project makespan. As indicated, to have a 60 percent probability of occurring, Rob will have to set the due date at 11 days (there is an actual probability of 0.84 that the project makespan will be 11 days or less).

Project Duration	Prob	Cum Prob
9	0.36	0.36
10	0.12	0.48
11	0.36	0.84
12	0.08	0.92
13	0.08	1.00

← Prob = 0.60

Part b) In reality, we should use all $3 \times 2 \times 2 \times 2 = 24$ realizations to find the true distribution of the project makespan. These 24 realizations are given in the following table:

Realization	Task (1,2)	Task (1,3)	Task (2,4)	Task (3,4)	Project Duration	Expected duration
1	2	1	7	10	11	0.018
2	2	1	7	2	9	0.018
3	2	1	9	10	11	0.012
4	2	1	9	2	11	0.012
5	2	4	7	10	14	0.162
6	2	4	7	2	9	0.162
7	2	4	9	10	14	0.108
8	2	4	9	2	11	0.108
9	3	1	7	10	11	0.006
10	3	1	7	2	10	0.006
11	3	1	9	10	12	0.004
12	3	1	9	2	12	0.004
13	3	4	7	10	14	0.054
14	3	4	7	2	10	0.054
15	3	4	9	10	14	0.036
16	3	4	9	2	12	0.036
17	4	1	7	10	11	0.006
18	4	1	7	2	11	0.006
19	4	1	9	10	13	0.004
20	4	1	9	2	13	0.004
21	4	4	7	10	14	0.054
22	4	4	7	2	11	0.054
23	4	4	9	10	14	0.036
24	4	4	9	2	13	0.036

Combining these values, we get the following discrete distribution of project makespan:

Project Duration	Prob	Cum Prob
9	0.18	0.18
10	0.06	0.24
11	0.222	0.462
12	0.044	0.506
13	0.044	0.55
14	0.45	1.00

12.062

← Prob = 0.60

This table indicates that the true expected makespan for this project is 12.062 (not 10.40 as indicated by the Classic PERT calculations).

Problem 6.3.

Task	DURATION (WKS)			Expected Duration	Standard Deviation	Mod Std Dev
	Optimistic	Most Likely	Pessimistic			
1	2	7	8	6.33	1.00	0.59
2	1	3	8	3.50	1.17	0.69
3	4	9	11	8.50	1.17	0.69
4	5	9	16	9.50	1.83	1.08

a) Expected longest path is Start-1-3-4-End with an expected duration = 24.33 weeks
variance = 5.72 weeks²
standard deviation = 2.39

$\Pr[z \leq (x - 24.33)/2.39] = 0.90$ which implies that $z = 1.28155$
thus, $(x - 24.33)/2.39 = 1.28155$ which implies that $x = 27.40$

b) Expected longest path has duration = 24.33
with variance = 1.98
and standard deviation = 1.407

$\Pr[z \leq (26 - 24.33)/1.407] = \Pr(z \leq 1.187) = 0.882$

Problem 6.4

Part a)

Task A		Task B		Task C	
Duration	Probability	Duration	Probability	Duration	Probability
2	0.3	5	0.5	4	0.45
3	0.7	10	0.5	6	0.55
mean	2.7	mean	7.5	mean	5.1

The expected critical (longest) path is START-A-B-END with an expected duration of 10.2
The Classic PERT model uses only information from this expected critical path for calculations
So calculating the 4 realizations for tasks A and B, we get:

Realization	Task A	Task B	Probability	Makespan	Cum prob
1	2	5	0.15	7	0.15
2	3	5	0.35	8	0.5
3	2	10	0.15	12	0.65
4	3	10	0.35	13	1

← Prob = 0.60

To have at least a 60 percent chance of occurring, Duncan should promise that the project will be completed in 12 days.

Part b) To find the true distribution for the project makespan, we must use both paths and all 8 realizations

Realization	Task A	Task B	Task C	Probability	Makespan
1	2	5	4	0.0675	7
2	2	5	6	0.0825	7
3	2	10	4	0.0675	12
4	2	10	6	0.0825	12
5	3	5	4	0.1575	8
6	3	5	6	0.1925	8
7	3	10	4	0.1575	13
8	3	10	6	0.1925	13

Makespan	Probability	Cum Prob
7	0.15	0.15
8	0.35	0.5
12	0.15	0.65
13	0.35	1

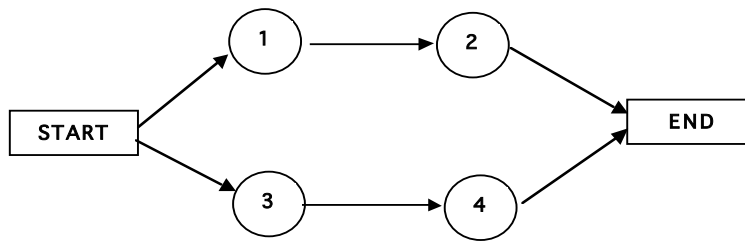
← Prob = 0.60

In this case, the distribution of the project makespan is the same as the one determined using the Classic PERT results (since the path START-A-B-END is longer in all cases than the path START-C-END).

The point of this problem is this: if the expected critical path identified by the Classic PERT model is sufficiently longer than any other path, the Classic PERT model is OK to use.

Problem 6.5

The precedence network in Problem 6.5 should read as follows (tasks should be numbered from 1 to 4):



Activity	Optimistic time	Most likely time	Pessimistic time	Expected duration	Variance
1	4	6	14	7.00	2.78
2	1	3	11	4.00	2.78
3	2	9	16	9.00	5.44
4	1	3	8	3.50	1.36

Path	E[Duration]	Variance	Orig. Schedule	Z score	Probability
START-1-2-END	11.00	5.56	13	0.85	0.802
START-3-4-END	12.50	6.81	13	0.19	0.576

Part a)

The Classic PERT model determined the expected critical path to be START-3-4-END, which gives an expected project duration of 12.50 (= 9.0 + 3.5) with an associated variance of 6.80 (=5.44 + 1.36)

Part b)

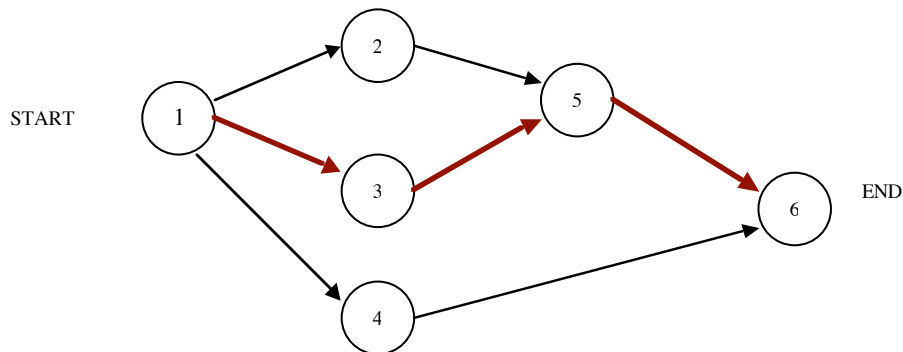
Using the Classic PERT model, the probability that the project will be completed within 13 weeks is $\Pr[ES_{END} \leq 13] = \Pr[z \leq .85] = .802$

Part c)

Since the two paths START-1-2-END and START-3-4-END are independent, the true probability that the project will be completed in 13 weeks is product of the probability that each path will be completed within 13 weeks. Thus, the true probability is $.802 \times .576 = 0.462$.

Problem 6.6

The AOA precedence network for this problem is:



Event I	Event j	Optimistic	Most Likely	Pessimistic	Expected Duration	Variance
1	2	1	1	7	2	1.00
1	3	1	4	7	4	1.00
1	4	2	7	9	6.5	1.36
2	5	1	1	1	1	0.00
3	5	2	2	14	4	4.00
4	6	2	6	10	6	1.78
5	6	3	3	15	5	4.00

Part a)

According to the Classic PERT model, the expected critical path is (1-3-5-6) with an expected length of 13 and a variance equal to $(1 + 4 + 4) = 9.0$

Thus, the probability that this project (according to Classic PERT) will be completed by week 11 (2 weeks early) is

$$\Pr[ES_{\text{END}} \leq 11] = \Pr[z \leq [(11 - 13)/3] = \Pr[z \leq -.667] = .252$$

Part b)

Let D = due date with a .90 probability of being met

Then, $\Pr[z \leq (D - 13)/3] = .90$

The value of z that corresponds to .90 is $z = 1.28$

So, $(D - 13)/3 = 1.28$ that results in a value of $D = 16.84$

Part c)

The probability that the longest expected path (1-3-5-6) is less than or equal to 16 weeks is

$$\Pr\{z \leq [(16-13)/3]\} = \Pr\{z \leq 1.0\} = .841$$

The second longest expected path in this network is (1-4-6) with an expected duration of 12.5 weeks and a variance equal to 3.14

The probability that this path is less than or equal to 16 weeks is

$$\Pr\{z \leq [(16 - 12.5)/1.772]\} = \Pr\{z \leq 1.975\} = .976$$

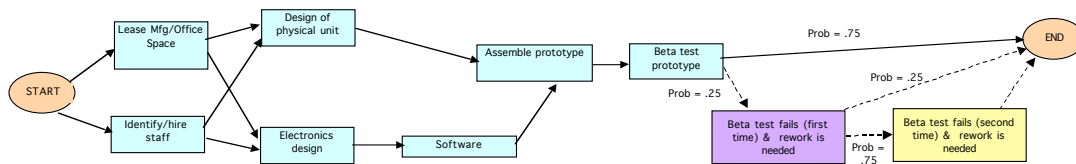
Assuming independence between the two paths, the probability that the project will be completed in less than 16 weeks is therefore the product $= .976 \times .841 = 0.82$ (that is lower than either path)

Problem 6.7. Based on the expected task durations, the expected critical path consists of the following tasks:

- A: Lease Mfg/Office Space (expected duration = 3.0)
- D: Electronics Design (expected duration = 5.5)
- E: Software (expected duration = 9.0)
- F: Assemble prototype (expected duration = 3.5)
- G: Beta test prototype (expected duration = 5.0)
- H: Beta test fails and rework needed (expected duration = $0.25 \times 23.5 = 5.875$)

The expected duration of this critical path is 31.875 that compares favorably with the makespan confidence intervals and expected makespan found by Monte Carlo simulation. In this case, the expected critical path is a reasonable approximation since there are relatively few paths in this network and the path START-A-D-E-F-G-H-END dominates the other paths. Nevertheless, the criticality indices indicate that there is an approximate 0.25 probability that tasks B (Identify/hire staff) and C (Design of physical unit) could be on the final critical path.

Problem 6.8. The network for this modified NPD project (that allows the possibility that the rework cycle could occur a maximum of two times) is as follows:



In this case, the simulation indicates that the expected makespan increases to approximately 35.5. See NPDx2_simulation.xls for more details and the simulation model for this problem.

Chapter 7: Risk Management

Solutions to Study Problems:

Problem 7.1

The project manager in the Van Allen case could decide to compress the project to 14 weeks and avoid the possibility of a strike. However, to do so would increase the total project costs to \$639.92 (from the current cost of \$619.92). This increased cost is found by adding a constraint to the Solver model that the finish time of the END milestone must be less than or equal to 14. Whether or not the project manager would want to incur this cost depends on how risk averse she is.

Problem 7.2

If we change the definition of the probability of a strike such that $\text{Pr}[\text{strike}] = \text{END}/(\text{END}+4)$ and rerun the Solver model, we find that the solution given in Table 7.6 remains optimal with the project duration at 17 weeks. However, since the probability of the strike increases to 0.81, the expected cost increase a bit to \$624.91. In this case, however, the solution is not always the same that is found when the probability of a strike is constant; if the indirect/overhead cost is very high, the project manager can reduce the expected project cost by compressing the project and reducing the expected cost of the strike.

Problem 7.3

Since the expected project completion time (in Table 7.6) is $17 + .7 \times 3.80 = 19.66$ weeks, there is no expected penalty given a due date of 20 weeks. Thus, the current optimal solution in Table 7.6 remains optimal; this can be verified by modifying the Excel spreadsheet model and rerunning Solver. (This, of course, is not always the case and will vary depending on the due date.)

Problem 7.4

The increased cost to reduce the project by more than 1.66 weeks is not worth the bonus of \$5/week. This can be verified by modifying the Excel model and rerunning Solver.

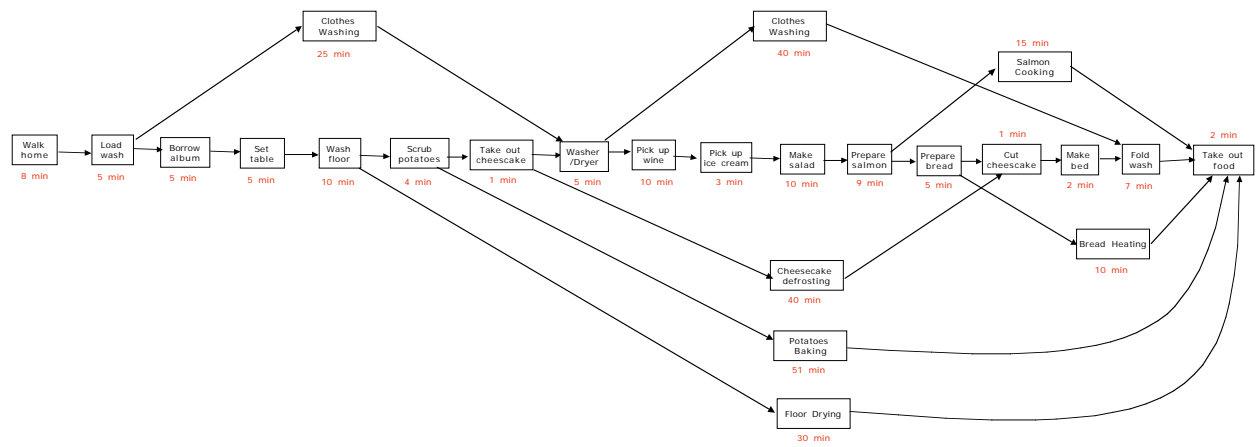
Chapter 8: Resource Management

Teaching Notes on Date Dilemma Caselet

This caselet is designed to introduce and reinforce two main lessons:

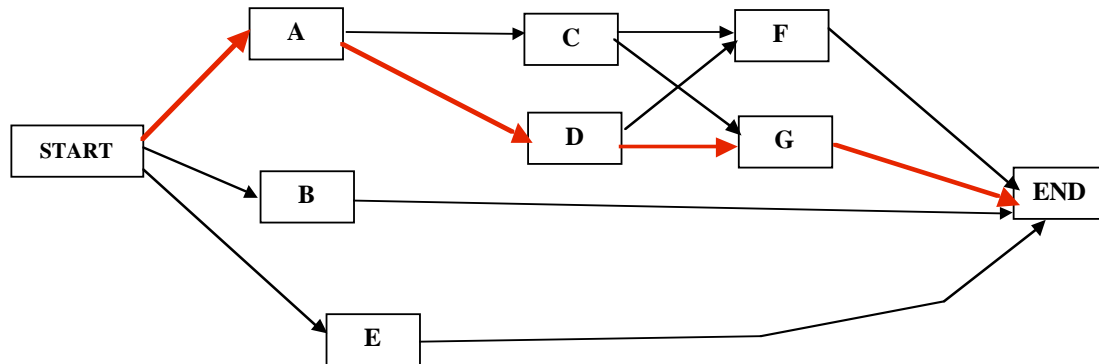
- 1) If tasks are not correctly defined, the resulting critical path analysis will be misleading at best (this reinforces the section in chapter 2 that discusses the proper definition of tasks in a WBS and points out that resource utilization should be a consideration when defining tasks). For example, the task “Bake Potatoes” that is estimated to take 55 minutes must be redefined into two tasks “Scrub and Butter Potatoes” (that takes 4 minutes and requires Jim as the resource) and “Cook Potatoes” (that takes 51 minutes and doesn’t require Jim but uses only the oven that we assume is not a constraining resource).
- 2) Resource constraints imply precedence relationships. Since Jim can only perform one task at a time, students quickly (I hope) learn that there must be precedence arcs between any tasks performed by Jim. Furthermore, in many cases, there is no easy way to determine which of Jim’s tasks should precede other tasks. For example, say that Jim must perform both tasks A and B. Since Jim can only perform one task at a time, task A must precede task B or vice versa. This gets us into a discussion of resource allocation and leveling and the difficult combinatorial nature of this problem.

As it turns out, Jim can complete all the specified tasks in exactly 90 minutes so most students state that Jim should not cut his accounting class. Of course, this leaves no slack for emergencies, etc. but that is another matter (relating to the risk management chapter). The AON network that represents this problem (there are other ways to define this network that also result in a 90 minute makespan) is given below. Some students may try to use MS Project to solve this problem; the resource leveling feature sometimes finds the best solution and sometimes not. This can also be used to generate a discussion on the nature of heuristics and how the quality of heuristics can be evaluated.



Solutions to Study Problems:

Problem 8.1



Task	Fast Contractor		Slow Contractor		Cost Diff
	Duration	Cost	Duration	Cost	
A	1.5	\$75	3	\$60	\$15
B	4	\$200	7	\$140	\$60
C	2	\$100	4	\$80	\$20
D	3	\$150	5	\$100	\$50
E	-		-		
F	1	\$50	3	\$60	-\$10
G	2	\$100	4	\$80	\$20

Notes: 1) Tasks A and B must be performed by the same contractor

2) The cost of task E (refilling the oil tank) is a constant that is equal to 15,000 gallons x \$1.75/gallon = \$26,250

3) The project must be completed within 9 days (at min cost)

If the slow contractor is hired for all tasks (to min costs) the critical path is 12 days (indicated in red)

For task F, the fast contractor actually costs less and takes less time...thus, we should always use the fast contractor on task F

The initial total cost for the project (ignoring the cost of refilling the oil tank) is \$510

To reduce the project duration to 10 days, we consider first Task A (on critical path) that has a cost difference between contractors of \$15; However, since we must hire the fast contractor for task B as well (total cost difference is then \$15 + \$20 = \$35, we hire the fast contractor for task G which compresses the project by 2 days for an increased cost of \$20.

The critical path remains START-A-D-G-END

Our choice at this point is either task A (and B), or task D. If we hire the fast contractor for both tasks A and B, it will cost us an additional \$15 + \$60 = \$75. So, we hire the fast contractor for task D at an additional cost of \$50.

The project is then completed in 8 days at a cost of \$510 + \$20 + \$50 = \$580.

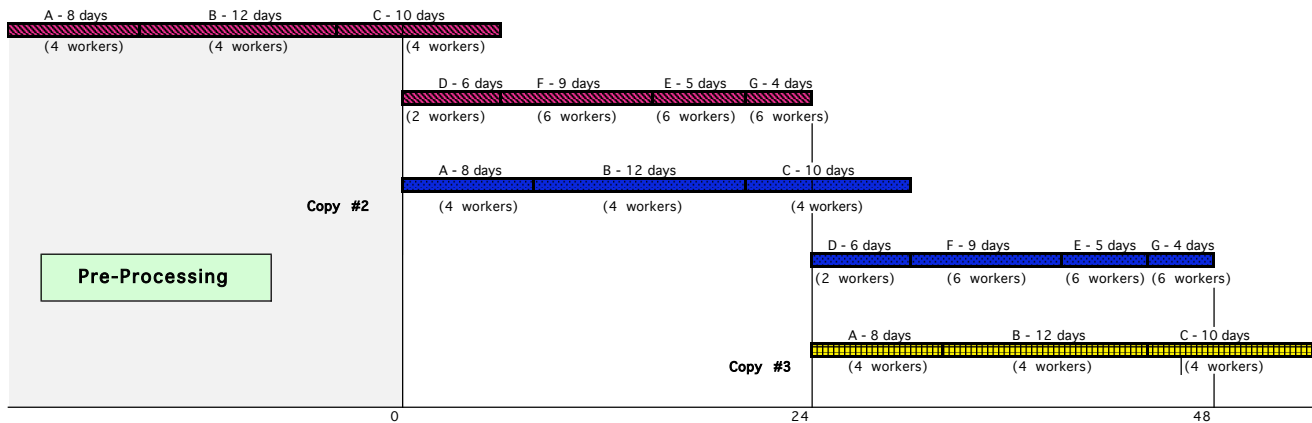
Problem 8.2.

It is possible to find a solution that uses 10 workers, by doing some pre-processing as indicated in the diagram below. The key to this solution is to overlap the production of widget copies and exploit the repetitive manufacturing nature of this production process. If you treat each widget produced as an independent project, the best solution uses 12 workers.

In the solution below, tasks are identified by letter while the tasks in the problem are identified by the (starting event, ending event) pair that is commonly used in AOA networks. The correspondence between the two is indicated below:

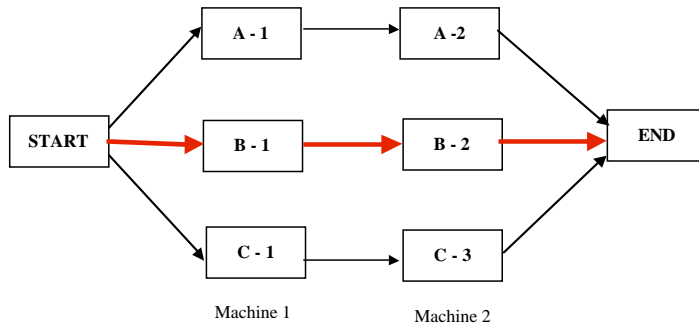
<u>Task</u>	<u>(Starting event, Ending event)</u>
A	(1, 2)
B	(1, 3)
C	(2, 3)
D	(2, 4)
E	(4, 5)
F	(3, 5)
G	(5, 6)

Frigid Midget Widget Company (10 worker solution)



Problem 8.3

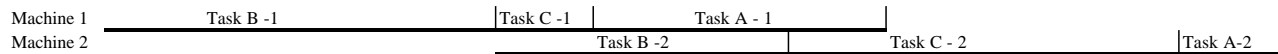
Part a) Ignoring resource constraints, the AON network is as follows:



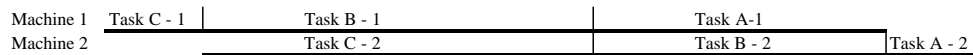
The project makespan (ignoring resource constraints) is 7 hours.

Task	Duration	Total Slack
A - 1	3	3
A - 2	1	3
B - 1	4	0
B - 2	3	0
C - 1	1	2
C - 2	4	2

Part b) If the manager sequences the jobs using total slack (with the highest priority to the jobs with the lowest slack), the sequence will be B, C, A that results in the a makespan of 12 as indicated below.



Using Johnson's rule, the optimal sequence that minimizes project makespan is C, B, A; the minimum makespan is 9.



Part c) The critical resources in this problem are machines 1 and 2.

Chapter 9: Monitoring and Control

Solutions to Study Problems:

Problem 9.1.

Part a)

$$\text{Schedule variance} = \text{BCWP} - \text{BCWS} = \$535,000 - \$523,000 = \$12,000$$

Part b)

$$\text{Schedule variance} = \text{BCWP} - \text{BCWS} = \$39,000 - \$42,000 = -\$3,000$$

$$\text{Cost variance} = \text{BCWP} - \text{ACWP} = \$39,000 - \$34,000 = \$5,000$$

Part c)

$$\text{Schedule index} = \text{BCWP}/\text{BCWS} = 0.96$$

$$\text{Cost index} = \text{BCWP}/\text{ACWP} = 1.04$$

Problem 9.2

Data

Task	Immediate Predecessor	Duration	Scheduled Cost/day
A	–	3	\$1,000
B	–	5	\$2,000
C	A	4	\$4,000
D	B	7	\$1,000
E	C	6	\$2,000
F	D	8	\$3,000

End of Week 1			End of Week 2	
Task	Actual % Completed	Cumulative Actual Cost	Actual % Completed	Cumulative Actual Cost
A	60%	\$1,500	100%	\$2,900
B	30%	\$3,000	100%	\$11,000
C	10%	\$2,000	100%	\$13,500
D	0%	\$0	90%	\$10,000
E	0%	\$0	50%	\$4,000
F	0%	\$0	0%	\$0

Solution

(a)

Planned work schedule and cost

End of Week 1			End of Week 2	
Task	% Completed	Cumulative Scheduled Cost	% Completed	Cumulative Scheduled Cost
A	100%	\$3,000	100%	\$3,000
B	100%	\$10,000	100%	\$10,000
C	50%	\$8,000	100%	\$16,000
D	0%	\$0	71%	\$5,000
E	0%	\$0	50%	\$6,000
F	0%	\$0	0%	\$0

Week 1	Task	BCWP	BCWS	ACWP	SV	CV	SI	CI
	A	\$1,800	\$3,000	\$1,500	(\$1,200)	\$300	0.6	1.2
	B	\$3,000	\$10,000	\$3,000	(\$7,000)	\$0	0.3	1
	C	\$1,600	\$8,000	\$2,000	(\$6,400)	(\$400)	0.2	0.8
	D	\$0	\$0	\$0	\$0	\$0	–	–
	E	\$0	\$0	\$0	\$0	\$0	–	–
	F	\$0	\$0	\$0	\$0	\$0	–	–
	Project	\$6,400	\$21,000	\$6,500	(\$14,600)	(\$100)	0.30	0.98

Week 2	Task	BCWP	BCWS	ACWP	SV	CV	SI	CI
	A	\$3,000	\$3,000	\$2,900	\$0	\$100	1	1.03
	B	\$10,000	\$10,000	\$11,000	\$0	(\$1,000)	1	0.91
	C	\$16,000	\$16,000	\$13,500	\$0	\$2,500	1	1.19
	D	\$6,300	\$5,000	\$10,000	\$1,300	(\$3,700)	1.26	0.63
	E	\$6,000	\$6,000	\$4,000	\$0	\$2,000	1	1.5
	F	\$0	\$0	\$0	\$0	\$0	–	–
	Project	\$41,300	\$40,000	\$41,400	\$1,300	(\$100)	1.03	0.998

(b)

The project Total Variance at the end of week 2 = **(\$1,400)**
 The scheduled project cycle (weeks) = **4**
 Time Variance (weeks) = **0.3**

(c)

At the end of week 1 the estimate total project cost = the original estimate approach **\$72,100** the revised estimate approach **\$73,125**

(d)

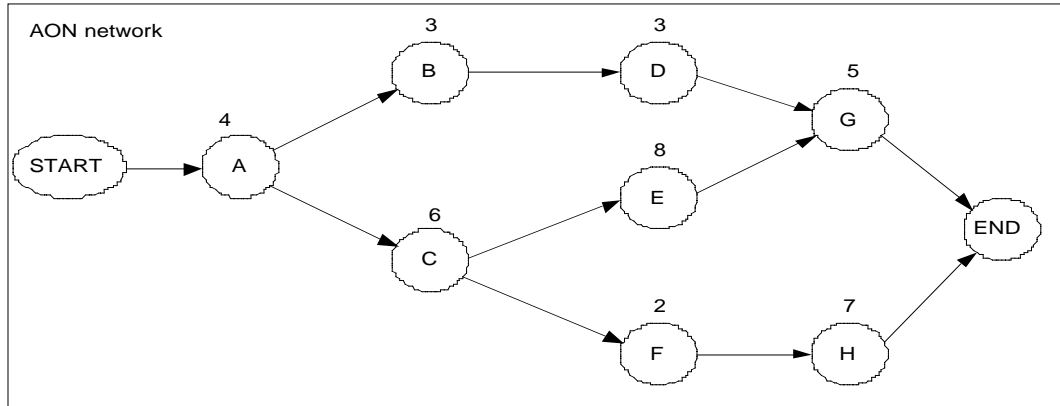
At the end of week 2 the estimate total project cost = the original estimate approach **\$72,100** the revised estimate approach **\$72,174**

Problem 9.3

Data

Module	Immediate Predecessors	Function Points	Budget (K)	Completed Function Point	Money Spent (K)
A	–	4	\$90	4	\$110
B	A	3	\$65	3	\$35
C	A	6	\$75	2	\$40
D	B	3	\$60	3	\$75
E	C	8	\$55	1	\$20
F	C	2	\$40	1	\$10
G	D, E	5	\$80	0	\$0
H	F	7	\$90	0	\$0

Solution



Module	BCWP	BCWS	ACWP	SV	CV	SI	CI
A	\$90	\$90	\$110	\$0	(\$20)	1.00	0.82
B	\$65	\$65	\$35	\$0	\$30	1.00	1.86
C	\$25	\$75	\$40	(\$50)	(\$15)	0.33	0.63
D	\$60	\$20	\$75	\$40	(\$15)	3.00	0.80
E	\$7	\$0	\$20	\$7	(\$13)	–	0.34
F	\$20	\$0	\$10	\$20	\$10	–	2.00
G	\$0	\$0	\$0	\$0	\$0	–	–
H	\$0	\$0	\$0	\$0	\$0	–	–
Project	\$267	\$250	\$290	\$17	(\$23)	1.07	0.92

According to Project SI alone, we conclude that the current project at week 8 is ahead of planned schedule.

However, if we include a CPM method in evaluating the project, we find that Module C is a critical task and currently two weeks delay. Therefore, without any crashing, actually the project will finish 2 weeks late.

Problem 9.4

Part a) As of the beginning of week 6:

Task	BCWS	ACWP	BCWP	Schedule Variance	Cost Variance
A	\$2,000	\$2,000	\$2,000	\$0	\$0
B	\$2,000	\$2,800	\$2,800	\$800	\$0
C	\$383	\$0	\$0	-\$383	\$0
D	\$250	\$330	\$344	\$94	\$14
E	\$0	\$0	\$0	\$0	\$0
F	\$0	\$0	\$0	\$0	\$0
G	\$0	\$0	\$0	\$0	\$0
Project	\$4,633	\$5,130	\$5,144	\$510	\$14

Part b) Since the schedule variance and cost variance for the project are greater than one, it would appear that the project is in control. However, due to the fact that task A (on the critical path) has been delayed, the project may be delayed.

Problem 9.5

Using a fixed 30/70 formula to compute BCWP:

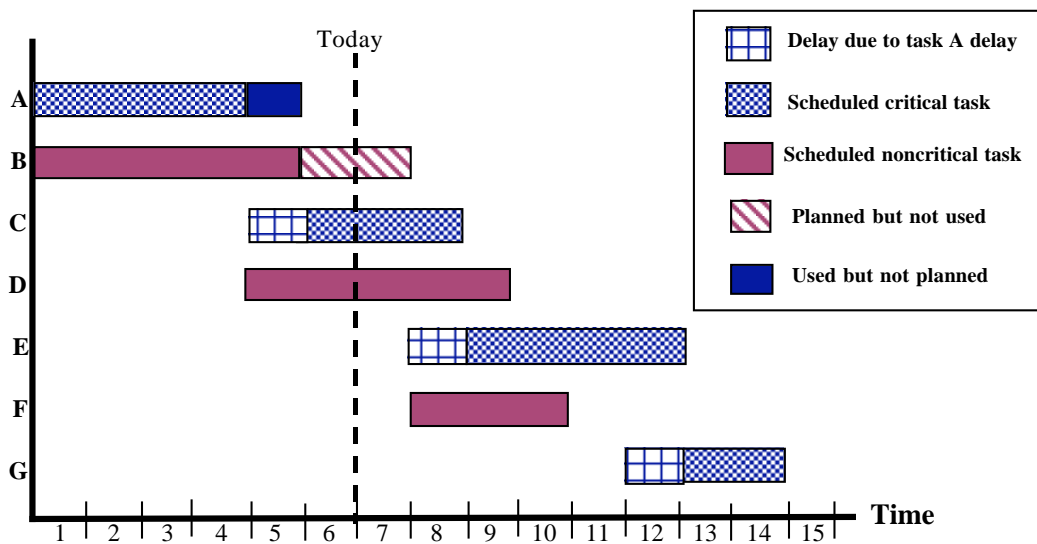
Task	BCWS	ACWP	BCWP	Schedule Variance	Cost Variance
A	\$2,000	\$2,000	\$2,000	\$0	\$0
B	\$2,000	\$2,800	\$2,800	\$800	\$0
C	\$383	\$0	\$345	-\$38	\$345
D	\$250	\$330	\$188	-\$63	-\$143
E	\$0	\$0	\$0	\$0	\$0
F	\$0	\$0	\$0	\$0	\$0
G	\$0	\$0	\$0	\$0	\$0
Project	\$4,633	\$5,130	\$5,333	\$699	\$203

Doesn't change my view of the project's status....

New Problem (not in text):

Problem 9.n:

Boyd Cycle is the project manager of a small project that consists of seven tasks. After careful and extensive planning, Boyd and his project staff agreed on a proposed project schedule and started the project six weeks ago. The original schedule as well as the current status of the project (at the beginning of the seventh week) is indicated in the following Gantt chart. As indicated, the start of task C was delayed due to the unexpected delay in completing task A; this, in turn, resulted in delaying the start of task C as well as the scheduled start of tasks E and G.



In their original project plan, Boyd and his staff had estimated the following task durations and (total) direct costs for each task; they assumed that direct labor efforts spent on each task would be approximately uniform for the estimated lifespan of each task.

Task	Duration (wks)	Planned Value
A	4	\$2,400
B	7	\$2,800
C	3	\$1,150
D	5	\$825
E	4	\$1,200
F	3	\$1,050
G	2	\$270

This morning (beginning of week 7), Boyd received a progress report; as indicated in the Gantt chart, the start of task C was delayed due to the unexpected delay in completing task A. The report also indicated that task B has been completed two weeks earlier than originally planned. Information from the progress report is summarized in the following table.

Task	Current Status	Actual Expenditures to date	Percent of work completed
A	Completed	\$2,550	100%
B	Completed	\$2,750	100%
C	In progress	\$250	30%
D	In progress	\$500	45%
E	Not started	\$0	0%
F	Not started	\$0	0%
G	Not started	\$0	0%

- As of today (beginning of week 7), what is the cost variance of the project? What is the schedule variance of the project?
- Based on information provided to date, what is your assessment of the current status of the project?
- If you use a fixed 15/85 formula to compute the value of the work completed (BCWP), what is the value of the cost index for the project? Schedule index for the project? Does this change your view of the project progress to date?

Solution to Problem 9.n:

a) As of the beginning of week 7:

Task	BCWS	ACWP	BCWP	Schedule Variance	Cost Variance
A	\$2,400	\$2,550	\$2,400	\$0	-\$150
B	\$2,400	\$2,750	\$2,800	\$400	\$50
C	\$767	\$250	\$345	-\$422	\$95
D	\$330	\$500	\$371	\$41	-\$129
E	\$0	\$0	\$0	\$0	\$0
F	\$0	\$0	\$0	\$0	\$0
G	\$0	\$0	\$0	\$0	\$0
Project	\$5,897	\$6,050	\$5,916	\$20	-\$134

b) Since the schedule variance is positive, it appears that the project is on schedule. However, based on the critical path, it appears to be behind schedule. The negative cost variance indicates a cost overrun.

c) Using a fixed 15/85 formula to compute BCWP:

Task	BCWS	ACWP	BCWP	Schedule Variance	Schedule Index	Cost Variance	Cost Index
A	\$2,400	\$2,550	\$2,400	\$0	100%	-\$150	94%
B	\$2,400	\$2,750	\$2,800	\$400	117%	\$50	102%
C	\$767	\$250	\$173	-\$594	23%	-\$78	69%
D	\$330	\$500	\$124	-\$206	38%	-\$376	25%
E	\$0	\$0	\$0	\$0	-	\$0	-
F	\$0	\$0	\$0	\$0	-	\$0	-
G	\$0	\$0	\$0	\$0	-	\$0	-
Project	\$5,897	\$6,050	\$5,496	-\$400	93%	-\$554	91%

Now it appears that both there is a project delay as well as a cost overrun.