A P P E N D I X   E

Case Studies

CHAPTER 2 CASES

2-1.[1] The Hi-V Company manufactures and cans three orange extracts: juice concentrate, regular juice, and jam. The products, which are intended for commercial use, are manufactured in 5-gallon cans. Jam uses Grade I oranges, and the remaining two products use Grade II. Table E.1 lists the usages of oranges as well as next year's demand. A market survey shows that the demand for regular juice is at least twice as high as that for the concentrate.

In the past, Hi-V bought Grade I and Grade II oranges separately at the respective prices of 25 cents and 20 cents per pound. This year, an unexpected frost forced growers to harvest and sell the crop early without being sorted to Grade I and Grade II. It is estimated that 30% of the 3,000,000-lb crop falls into Grade I and only 60% into Grade II. For this reason, the crop is being offered at the uniform discount price of 19 cents per pound. Hi-C estimates that it will cost the company about 2.15 cents per pound to sort the oranges into Grade I and Grade II. The below-standard oranges (10% of the crop) will be discarded.

For the purpose of cost allocation, the accounting department uses the following argument to estimate the cost per pound of Grade I and Grade II oranges. Because 10% of the purchased crop will fall below the Grade II standard, the effective average cost per pound can be computed as $\frac{(19 + 2.15)}{.9} = 23.5$ cents. Given that the ratio of Grade I to Grade II in the purchased lot is 1 to 2, the corresponding average cost per pound based on the old prices is $\frac{(20 \times 2 + 25 \times 1)}{3} = 21.67$ cents. Thus, the increase in the average price $(= 23.5 \text{ cents} - 21.67 \text{ cents} = 1.83 \text{ cents})$ should be reallocated to the two grades by a 1:2 ratio, yielding a Grade I cost per pound of $20 + 1.83\left(\frac{1}{3}\right) = 21.22$ cents and a Grade II cost of $25 + 1.83\left(\frac{2}{3}\right) = 25.61$ cents. Using this information, the accounting department compiles the profitability sheet for the three products in Table E.2.

Establish a production plan for the Hi-C Company.

[1]Motivated by "Red Brand Canners," *Stanford Business Cases 1965*, Graduate School of Business, Stanford University.

TABLE E.1

Product	Orange grade	Pounds of oranges per 5-gal can	Maximum demand (cans)
Jam	I	5	10,000
Concentrate	II	30	12,000
Juice	II	15	40,000

TABLE E.2

	Product (5-gal can)		
	Jam	*Concentrate*	*Juice*
Sales price	\$15.50	\$30.25	\$20.75
Variable costs	9.85	21.05	13.28
Allocated fixed overhead	1.05	2.15	1.96
Total cost	\$10.90	\$23.20	\$15.24
Net profit	4.60	7.05	5.51

2-2.[2] A steel company operates a foundry and two mills. The foundry casts three types of steel rolls that are machined in its machine shop before being shipped to the mills. Machined rolls are used by the mills to manufacture various products.

At the beginning of each quarter, the mills prepare their monthly needs of rolls and submit them to the foundry. The foundry manager then draws a production plan that is essentially constrained by the machining capacity of the shop. Shortages are covered by direct purchase at a premium price from outside sources. A comparison between the cost per roll when acquired from the foundry and its outside purchase price is given in Table E.3. However, management points out that such shortage is not frequent and can be estimated to occur about 5% of the time.

The processing times on the four different machines in the machine shop are given in Table E.4. The demand for rolls by the two mills over the next 3 months is given in Table E.5.

TABLE E.3

Roll type	Weight (lb)	Internal cost (\$ per roll)	External purchase price (\$ per roll)
1	800	90	108
2	1200	130	145
3	1650	180	194

[2]Based on S. Jain, K. Stott, and E. Vasold, "Orderbook Balancing Using a Combination of Linear Programming and Heuristic Techniques," *Interfaces*, Vol. 9, No. 1, pp. 55–67, 1978.

TABLE E.4

Machine type	Processing time per roll: *Roll 1*	*Roll 2*	*Roll 3*	Number of machines	Available hr per machine per month
1	1	5	7	10	320
2	0	4	6	8	310
3	6	3	0	9	300
4	3	6	9	5	310

TABLE E.5

	Demand in rolls					
	Mill 1			Mill 2		
Month	*Roll 1*	*Roll 2*	*Roll 3*	*Roll 1*	*Roll 2*	*Roll 3*
1	500	200	400	200	100	0
2	0	300	500	300	200	200
3	100	0	300	0	400	200

Devise a production schedule for the machine shop.

2-3. ArkTec assembles PC computers for private clients. The orders for the next four quarters are 400, 700, 500, and 200, respectively. ArkTec has the option to produce more than is demanded for the quarter, in which case a holding cost of $100 per computer per quarter is incurred. Increasing production from one quarter to the next requires hiring additional employees, which increases the production cost per computer in that quarter by $60. Also, decreasing production from one quarter to the next would require laying off employees, which results in increasing the production cost per computer in that quarter by $50.

How should ArkTec schedule the assembly of the computers to satisfy the demand for the four quarters?

2-4. The Beaver Furniture Company manufactures and assembles chairs, tables, and bookshelves. The plant produces semifinished products that are assembled in the company's assembling facility. The (unassembled) monthly production capacity of the plant includes 3000 chairs, 1000 tables, and 580 bookshelves. The assembling facility employs 150 workers in two 8-hour shifts a day, 5 days a week. The average assembly times per chair, table, and bookshelf are 20, 40, and 15 minutes, respectively.

The size of the labor force in the assembly facility fluctuates because of the annual leaves taken by the employees. Pending requests for leaves include 20 workers for May, 25 for June, and 45 for July. Sales of the three products for the months of May, June, and July are forecast by the marketing department as given in Table E.6. The production cost and selling price for the three products are shown in Table E.7. If a unit is not sold in the month in which it is produced, it is held over for possible sale in a later month. The storage cost is about 2% of the unit production cost.

Should Beaver approve the proposed annual leaves?

TABLE E.6

Product	Sales forecast units			End-of-April inventory
	May	*June*	*July*	
Chair	2800	2300	3350	30
Table	500	800	1400	100
Bookshelf	320	300	600	50

TABLE E.7

Product	Unit cost ($)	Unit price ($)
Chair	150	250
Table	400	750
Bookshelf	60	120

CHAPTER 3 CASES

3-1. A small canning company produces five types of canned goods that are extracted from three types of fresh fruit. The manufacturing process uses two production departments that were originally designed with surplus capacities to accommodate possible future expansion. In fact, the company operates currently on a one-shift basis and can easily expand to two or three shifts to meet increase in demand. The real restriction for the time being appears to be the limited availability of fresh fruit. Because of the limited refrigeration capacity on the company's premises, fresh fruit must be brought in daily.

A young operations researcher has just joined the company. After analyzing the production situation, the analyst decides to formulate a master LP model for the plant. The model involves five decision variables (for the five products) and three constraints (for the raw materials). With three constraints and five variables, LP theory says that the optimum solution cannot include more than three products. "Aha," the analyst says, "the company is not operating optimally!"

The analyst schedules a meeting with the plant manager to discuss the details of the LP model. The manager, who seems to follow the modeling concept well, agrees with the analyst that the model is a close representation of reality. The analyst then goes on to explain that, according to LP theory, the optimal number of products should not exceed three because the model has only three constraints. As such, it may be worthwhile to consider discontinuing the two nonprofitable products.

The manager listens attentively, then tells the analyst that the company is committed to producing all five products because of the competitive nature of the market and that in no way can the company discontinue any of the products. The operations researcher responds that the only way to remedy the situation is to add at least two more constraints, in which case the optimal LP model is likely to include all five products. At this point the manager gets confused, because the idea of having to add more restrictions to be able to produce more products does not suggest optimality. "That is what the LP theory says," is the analyst's answer.

What is your opinion of this "paradox"?

3-2.[3] An LTL trucking company, specializing in less-than-truckload shipments, operates a number of terminals that are strategically located across the United States. When the loads arrive at a terminal, they are sorted either for delivery to local customers or for transfer to other terminals. The terminal docks are staffed by *bid* and *casual* workers. *Bid* workers are union employees who are guaranteed a 40-hour work-week. A bid employee assigned to one of the standard three shifts of the day is expected to work the same shift for five consecutive days, but may start on any day of the week. *Casual* employees are hired temporarily for any number of hours to account for peak loads that may exceed the work capacity of available bid workers. Union contract restricts casual employees to less than 40 hours per week.

Loads arrive at the terminal at all hours of the day and, for all practical purposes, their level varies continuously with the time of the day. A study of historical data shows that the load level takes on a repetitive weekly pattern that peaks during the weekend (Friday through Sunday). The company's policy specifies that a load must be processed within 16 hours of its arrival at the terminal.

Develop a model to determine the weekly assignment of bid workers

3-3.[4] The Elk Hills oil field has a majority ownership (80%) by the U.S. Federal Government. The Department of Energy (DOE) is authorized by law to sell the government's share of the oil produced to the highest qualified bidders. At the same time, the law limits the quantity of oil delivered to any one bidder. The oil field has six delivery points with different production capacities (bbl/day). The amounts of daily production (in bbl/day) at each of the delivery points are presented daily as *line items*, and a bidder may submit bids on any number of line items. DOE collects the bids and evaluates them, starting with line item 1 and terminating with line item 6, awarding delivery to the highest bidder but taking into account the caps set by law on the quantity of oil any one bidder can receive. To be specific, Table E.8 provides a summary of bonus prices bid on a certain day. A bonus is an increment over the highest price offered for similar grade oil produced in the delivery point area. No bidder can receive more than 20% of the total daily production of 180,000 bbl from all delivery points.

TABLE E.8

	Bonus in $/bbl bid by bidder								
Line item	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	Production (1000 bbl/day)
1	1.10	.99	1.20	1.10	.95	1.00	1.05	1.02	20
2	1.05	1.02	1.12	1.08	1.09	1.06	1.11	1.07	30
3	1.00	.95	.97	.94	.93	1.01	1.02	.98	25
4	1.30	1.25	1.31	1.27	1.28	1.26	1.32	1.32	40
5	1.09	1.12	1.15	1.07	1.08	1.11	1.05	1.10	35
6	.89	.87	.90	.86	.85	.91	.88	.91	30

[3]Based on a study conducted by the author for a national LTL trucking company.
[4]Based on B. Jackson and J. Brown, "Using LP for Crude Oil Sales at Elk Hills: A Case Study," *Interfaces*, Vol. 10, pp. 65–69, No. 3, 1980.

DOE uses a ranking scheme for awarding the bids. Starting with line item 1, bidder 3 has the highest bid (bonus = \$1.20) and hence is awarded the maximum amount allowed by both line item 1 production and the 20% limit imposed by law ($= .2 \times 180{,}000 = 36{,}000$ bbl). From the data in the table, all line 1 item production (20,000 bbl) is allocated to bidder 3. Moving to line item 2, bidder 3 again offers the highest bonus but can only be awarded a maximum of 16,000 bbl because of the 20% limit. The remaining quantity is assigned to the bidder with the next-best bonus (= \$1.11), thus allocating 14,000 bbl ($= 30{,}000 - 16{,}000$) to bidder 7. The process is repeated until line item 6 is awarded.

Does the proposed scheme guarantee maximum daily revenue for the government? Can the government do better by changing the 20% limit either up or down?

CHAPTER 4 CASES

4-1.[5] MANCO produces three products *P*1, *P*2, and *P*3. The production process uses raw materials *R*1 and *R*2, which are processed on facilities *F*1 and *F*2. Table E.9 provides the pertinent data of the problem. The minimum daily demand for *P*2 is 70 units and the maximum demand for *P*3 is 240 units. The unit revenue contributions of *P*1, *P*2, and *P*3 are \$300, \$200, and \$500, respectively.

MANCO management is exploring means to improve the financial situation of the company. Discuss the feasibility of the following proposals:

1. The per-unit revenue of P3 can be increased by 20%, but this will reduce the market demand to 210 units instead of the present 240 units.
2. Raw material *R*2 appears to be a critical factor in limiting current production. Additional units can be secured from a different supplier whose price per pound is \$3 higher than that of the present supplier.
3. The capacities of *F*1 and *F*2 can be increased by up to 40 minutes a day, each for an additional cost of \$35 per day.
4. The chief buyer of product *P*2 is requesting that its daily supply be increased from the present 70 units to 100 units.
5. The per unit processing time of *P*1 on *F*2 can be reduced from 3 to 2 minutes at an additional cost of \$4 per day.

TABLE E.9

		Usage per unit			
Resource	Units	*P1*	*P2*	*P3*	Maximum daily capacity
*F*1	Minutes	1	2	1	430
*F*2	Minutes	3	0	2	460
*R*1	lb	1	4	0	420
*R*2	lb	1	1	1	300

[5]Based on D. Sheran, "Post-Optimal Analysis in Linear Programming—The Right Example," *IIE Transactions*, Vol. 16, No. 1, pp. 99–102, March 1984.

4-2. The Reddy Mikks Company is preparing a future expansion plan. A study of the market indicates that the company can increase its sales by about 25%. The following proposals are being studied for the development of an action plan. (Refer to Example 3.3-1 for the details of the model and its solution.)

Proposal 1. Because a 25% increase roughly equals a \$5250 increase in revenue and the worths per additional ton of $M1$ and $M2$ are \$750 and \$500, respectively, the desired increase in production can be achieved by making a combined increase of $\$250 \div \frac{(\$750\ +\ \$500)}{2} = 8.4$ tons in each of $M1$ and $M2$.

Proposal 2. Increase the amounts of raw materials $M1$ and $M2$ by 6 tons and 1 ton, respectively. These increments equal 25% of the current levels of $M1$ and $M2$ (= 24 and 6 tons, respectively). Because these two resources are *scarce* at the current optimum solution, a 25% increase in their availability produces an equivalent increase in the levels of production of interior and exterior paints, as desired.

What is your opinion of these proposals? Would you suggest a different approach for solving the problem?

CHAPTER 5 CASES

5-1.[6] ABC Cola operates a plant in the northern section of the island nation of Tawanda. The plant produces soft drinks in three types of packages that include returnable glass bottles, aluminum cans, and nonreturnable plastic bottles. Returnable (empty) bottles are shipped to the distribution warehouses for reuse in the plant.

Because of the continued growth in demand, ABC wants to build another plant. The demand for the soft drinks (expressed in cases) over the next 5 years is given in Table E.10. The planned production capacities for the existing plant extrapolated over the same 5-year horizon are given in Table E.11. The company owns six distribution warehouses: $N1$ and $N2$ are located in the north, $C1$ and $C2$ in the central section, and $S1$ and $S2$ in the south. The share of sales by each warehouse within its zone is given in Table E.12. Approximately 60% of the sales occur in the north, 15% in the central section, and 25% in the south.

The company wants to construct the new plant either in the central section or in the south. The transportation cost per case of returnable bottles is given in Table E.13. It is estimated that the transportation costs per case of cans and per case of nonreturnables are, respectively, 60% and 70% of that of the returnable bottles.

Should the new plant be located in the central or the southern section of the country?

TABLE E.10

	Year				
Package	*1*	*2*	*3*	*4*	*5*
Returnables	2400	2450	2600	2800	3100
Cans	1750	2000	2300	2650	3050
Nonreturnables	490	550	600	650	720

[6]Based on T. Cheng and C. Chiu, "A Case Study of Production Expansion Planning in a Soft-Drink Manufacturing Company," *Omega*, Vol. 16, No. 6, pp. 521–532, 1988.

TABLE E.11

Package	Year				
	1	*2*	*3*	*4*	*5*
Returnables	1800	1400	1900	2050	2150
Cans	1250	1350	1400	1500	1800
Nonreturnables	350	380	400	400	450

TABLE E.12

Warehouse	Share percentage
*N*1	85
*N*2	15
*C*1	60
*C*2	40
*S*1	80
*S*2	20

TABLE E.13

Warehouse	Transportation cost per case ($)		
	Existing plant	*Central plant*	*South plant*
*N*1	0.80	1.30	1.90
*N*2	1.20	1.90	2.90
*C*1	1.50	1.05	1.20
*C*2	1.60	0.80	1.60
*S*1	1.90	1.50	0.90
*S*2	2.10	1.70	0.80

5-2.[7] The construction of Brisbane International Airport requires the pipeline movement of about 1,355,000 m^3 of sand dredged from five clusters at a nearby bay to nine sites at the airport location. The sand is used to help stabilize the swampy grounds at the proposed construction area. Some of the sites to which the sand is moved are dedicated to building roads both within and on the perimeter of the airport. Excess sand from a site will be moved by trucks to other outlying areas around the airport, where a perimeter road will be built. The distances (in 100 m) between the source clusters and the sites are summarized in Table E.14. The table also shows the supply and demand quantities in 100 m^3 at the different locations.

(a) The project management has estimated a [volume $(m^3) \times$ distance (100 m)] sand movement of 2,495,000 units at the cost of $.65 per unit. Is the estimate given by the project management for sand movement on target?

[7]Based on C. Perry and M. Ilief, "Earth Moving on Construction Projects," *Interfaces*, Vol. 13, No. 1, pp. 79–84, 1983.

TABLE E.14

	1	2	3	4	5	6	7	8	9	Supply
1	22	26	12	10	18	18	11	8.5	20	**960**
2	20	28	14	12	20	20	13	10	22	**201**
3	16	20	26	20	1.5	28	6	22	18	**71**
4	20	22	26	22	6	∞	2	21	18	**24**
5	22	26	10	4	16	∞	24	14	21	**99**
Demand	**62**	**217**	**444**	**315**	**50**	**7**	**20**	**90**	**150**	

(b) The project management has realized that sand movement to certain sites cannot be carried out until some of the roads are built. In particular, the perimeter road (destination 9) must be built before movement to certain sites can be done. In Table E.15, the blocked routes that require the completion of the perimeter road are marked with x. In view of these restrictions, how should the sand movement be made?

5-3. Ten years ago, a wholesale dealer started a business distributing pharmaceuticals from a central warehouse (*CW*). Orders were delivered to customers by vans. The warehouse has since been expanded in response to growing demand. Additionally, two new warehouses (*W*1 and *W*2) have been constructed. The central warehouse, traditionally well stocked, occasionally supplies the new warehouses with some short items. The occasional supply of short items has grown into a large-scale operation in which the two new warehouses receive for redistribution about one-third of their stock directly from the central warehouse. Table E.16 gives the number of orders shipped out by each of the three warehouses to customer locations *C*1 to *C*6. A customer location is a town with several pharmacies.

The dealer's delivery schedule has evolved over the years to its present status. In essence, the schedule was devised in a rather decentralized fashion, with each warehouse determining its delivery zone based on "self-fulfilling" criteria. Indeed, in some instances, warehouse managers competed for new customers mainly to increase their "sphere of influence." For instance, the managers of the central warehouse boast that

TABLE E.15

	1	2	3	4	5	6	7	8	9
1	x	x			x				
2	x	x			x				
3			x			x			
4			x					x	
5	x	x			x		x		

TABLE E.16

Route		
From	*To*	No. of orders
CW	*W*1	2000
CW	*W*2	1500
CW	*C*1	4800
CW	*C*2	3000
CW	*C*3	1200
*W*1	*C*1	1000
*W*1	*C*3	1100
*W*1	*C*4	1500
*W*1	*C*5	1800
*W*2	*C*2	1900
*W*2	*C*5	600
*W*2	*C*6	2200

their delivery zone includes not only regular customers but the other two warehouses as well. It is not unusual, then, that several warehouses deliver supplies to different pharmacies within the same town (customer location).

The distances in miles traveled by vans between locations are given in Table E.17. A vanload usually hauls 100 orders. Evaluate the present distribution policy of the dealer.

5-4. Kee Wee Airlines flies eight two-way flights between Waco and Macon according to the schedule in Table E.18. A crew can return to its home base (Waco or Macon) on the same day, provided there is at least a 90-minute layover in the other city. Otherwise, the crew can return the next day. It is desired to pair the crews with the flights originating from the two cities to minimize the total layover time of all the crews.

TABLE E.17

	CW	*W*1	*W*2	*C*1	*C*2	*C*3	*C*4	*C*5	*C*6
CW	0	5	45	50	30	30	60	75	80
*W*1	5	0	80	38	70	30	8	10	60
*W*2	45	80	0	85	35	60	55	7	90
*C*1	50	38	85	0	20	40	25	30	70
*C*2	30	70	35	20	0	40	90	15	10
*C*3	30	30	60	40	40	0	10	6	90
*C*4	60	8	55	25	90	10	0	80	40
*C*5	75	10	7	30	15	6	80	0	15
*C*6	80	60	90	70	10	90	40	15	0

TABLE E.18					
Flight	From Waco	To Macon	Flight	From Macon	To Waco
$W1$	6:00	8:30	$M1$	7:30	9:30
$W2$	8:15	10:45	$M2$	9:15	11:15
$W3$	13:30	16:00	$M3$	16:30	18:30
$W4$	15:00	17:30	$M4$	20:00	22:00

CHAPTER 6 CASES

6-1. An outdoors person who lives in San Francisco (SF) wishes to spend a 15-day vacation visiting four national parks: Yosemite (YO), Yellowstone (YE), Grand Teton (GT), and Mount Rushmore (MR). The tour, which starts and ends in San Francisco, visits the parks in the order SF → YO → YE → GT → MR → SF, and includes a 2-day stay at each park. Travel from one park location to another is either by air or car. Each leg of the trip takes 1/2 day if traveled by air. Travel by car takes 1/2 day from SF to YO, 3 days from YO to YE, one day from YE to GT, 2 days from GT to MR, and 3 days from MR back to SF. The tradeoff is that car travel generally costs less but takes longer. Considering that the individual must return to work in 15 days, the objective is to make the tour as inexpensively as possible within the 15-day limit. Table E.19 provides the one-way cost of traveling by car and air. Determine the mode of travel on each leg of the tour.

6-2.[8] A benefactor has donated books to the Springdale Public Library. The books come in four heights: 12, 10, 8, and 6 inches. The head librarian estimates that 12 feet of shelving will be needed for the 12-inch books, 18 feet for the 10-inch ones, 9 feet for the 8-inch books, and 10 feet for the 6-inch ones. The construction cost of a shelf includes both a fixed cost and a variable cost per foot length, as Table E.20 shows.

Given that smaller books can be stored on larger shelves, how should the shelves be designed?

6-3. A shipping company wants to deliver five cargo shipments from ports *A*, *B*, and *C* to ports *D* and *E*. The delivery dates for the five shipments are given in Table E.21. Table E.22 gives trip times (in days) between ports (the return trip is assumed to take less time). The company wants to determine the minimum number of ships needed to carry out the given shipping schedule.

TABLE E.19	Air travel cost ($) to					Car travel cost ($) to				
From	*SF*	*YO*	*YE*	*GT*	*MR*	*SF*	*YO*	*YE*	*GT*	*MR*
SF	—	150	350	380	450	—	130	175	200	230
YO	150	—	400	290	340	130	—	200	145	180
YE	350	400	—	150	320	175	200	—	70	150
GT	380	290	150	—	300	200	145	70	—	100
MR	450	340	320	300	—	230	180	150	100	—

[8]Based on A. Ravindran, "On Compact Storage in Libraries," *Opsearch,* Vol.8, No. 3, pp.245–252, 1971.

TABLE E.20

Shelf height (in.)	Fixed cost ($)	Variable cost ($/ft length)
12	25	5.50
10	25	4.50
8	22	3.50
6	22	2.50

TABLE E.21

Shipment	Shipping route	Delivery date
1	*A* to *D*	10
2	*A* to *E*	15
3	*B* to *D*	4
4	*B* to *E*	5
5	*C* to *E*	18

6-4.[9] Several individuals set up unregulated brokerage firms overseas that traded in highly speculative stocks. The brokers operated under a loose financial system that allowed extensive interbrokerage transactions, including buying, selling, borrowing, and lending. For the group of brokers as a whole, the main source of income was the commission they received from sales to outside clients.

Eventually, the risky trading in speculative stocks became unmanageable, and all the brokers declared bankruptcy. The financial situation at the time was that all brokers owed money to outside clients, and the interbroker financial entanglements were so complex that almost every broker owed money to every other broker in the group.

TABLE E.22

	A	B	C	D	E
A				3	4
B				3	2
C				3	5
D	2	2	2		
E	3	1	4		

[9]Based on H. Taha, "Operations Research Analysis of a Stock Market Problem," *Computers and Operations Research,* Vol. 18, No. 7, pp. 597–602, 1991.

The brokers whose assets could pay for their debts were declared solvent. The remaining brokers were referred to a legal body whose purpose was to resolve the debt situation in the best interest of outside clients. Because the assets and receivables of the nonsolvent brokers were less than their payables, all debts were prorated. The final effect was a complete liquidation of all the assets of the nonsolvent brokers.

In resolving the financial entanglements within the group of nonsolvent brokers, it was decided that the transactions would be executed only to satisfy certain legal requirements because, in effect, none of the brokers would be keeping any of the funds owed by others. The legal body requested that the number of interbroker transactions be reduced to an absolute minimum. This meant that if A owed B an amount X, and B owed A an amount Y, the two "loop" transactions were reduced to one whose amount was $|X - Y|$. This amount would go from A to B if $X > Y$ and from B to A if $Y > X$. If $X = Y$, the transactions were completely eliminated. The idea was to be extended to all loop transactions involving any number of brokers.

How would you handle this situation? Specifically, you are required to answer two questions.

1. How should the debts be prorated?

2. How should the number of interbroker transactions be reduced to a minimum?

CHAPTER 7 COMPREHENSIVE PROBLEMS

7-1. Suppose that you are given the points

$$A = (6, 4, 6, -2), B = (4, 12, -4, 8), C = (-4, 0, 8, 4)$$

Develop a systematic procedure that will allow determining whether or not each of the following points can expressed as a convex combination of *A,* B, and *C:*

(a) $(3, 5, 4, 2)$

(b) $(5, 8, 4, 9)$

7-2. Consider the following LP:

$$\text{Maximize } z = 3x_1 + 2x_2$$

Subject to

$$x_1 + 2x_2 \le 6$$
$$2x_1 + x_2 \le 8$$
$$-x_1 + x_2 \le 1$$
$$x_1, x_2 \ge 0$$

Determine the optimum simplex tableau (use TORA for convenience), and then directly use the information in the optimum simplex tableau to determine the *second*-best extreme-point solution (relative to the "absolute" optimum) for the problem. Verify the answer by solving the problem graphically. (*Hint:* Consult the extreme points that are *adjacent* to the optimum solution.)

7-3.[10] The trim-loss model of Example 2.3-9 assumes that *all* the knife settings are determined in advance. In reality, we can use the revised simplex method with imbedded integer linear programs (ILPs) to generate promising knife settings using the following **column generation** procedure:

Step 0 (Starting solution): Select the obvious starting basic feasible solution that consists of exactly one roll of each of the desired widths. For instance, in Example 2.3-9, the basic solution $\mathbf{X}_{\mathbf{B}_0} = (x_1, x_2, x_3)^T$ corresponds to the following basis:

$$\mathbf{B}_0 = \begin{matrix} x_1 & x_2 & x_3 & \\ \begin{pmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{pmatrix} & & & \begin{matrix} \leftarrow 5 \text{ ft} \\ \leftarrow 7 \text{ ft} \\ \leftarrow 9 \text{ ft} \end{matrix} \end{matrix}$$

The basis corresponds to cutting 150, 200, and 300 standard rolls to produce the 5-ft, 7-ft, and 9-ft rolls, respectively. The amount of trim loss is unimportant at this point. Using the notation of the revised simplex method, this solution corresponds to

$$\mathbf{B}_0 = \mathbf{B}_0^{-1} = \mathbf{I}$$

$$\mathbf{c}_B\mathbf{B}_0^{-1} = (1, 1, 1)$$

Step j (Promising knife setting): Let $\mathbf{B}_{j-1}^{-1}$ be the inverse basis associated with knife settings combination $j - 1$. The jth knife setting can be represented by the column vector $\mathbf{P}_j = (a_1, a_2, \ldots, a_m)^T$, where m is the number of special rolls that can be cut from a single standard roll and a_i is the number of rolls of type $i, i = 1, 2, \ldots, m$. For instance, in Example 2.3-9, $m = 3$ and the setting $(2, 1, 0)$ produces two 5-ft rolls, one 7-ft roll, and zero 9-ft roll. The objective is to determine the elements of $\mathbf{P}_j$ that will make the associated variable x_j basic in the next iteration. This is equivalent to determining $\mathbf{P}_j$ that will result in the largest reduced cost, $z_j - c_j$, provided that the associated knife settings $a_1, a_2, \ldots$, and a_n are feasible (recall that the trim-loss model is a minimization problem). Let W be the width of the standard roll and $\mathbf{w} = (w_1, w_2, \ldots, w_m)$ represent the widths of the ordered rolls. The determination of the most promising $\mathbf{P}_j$ is thus equivalent to solving the following integer linear program

$$\text{Maximize } z_j - c_j = \mathbf{c}_B\mathbf{B}_{j-1}^{-1}\mathbf{P}_j - c_j$$

subject to

$$\mathbf{w}\mathbf{P}_j \leq W$$

$$\mathbf{P}_j \geq \mathbf{0} \text{ and integer}$$

The trim-loss problem $c_j = 1$ for all j, hence $\mathbf{c}_B = (1, 1, \ldots, 1)$. Letting $(d_1, d_2, \ldots, d_m) = \mathbf{c}_B\mathbf{B}_{j-1}^{-1}$ represent the dual variables associated with basis $\mathbf{B}_{j-1}^{-1}$, we can write the ILP as

$$\text{Maximize } z = \sum_{k=1}^{n} d_k a_k$$

---

[10]Based on P. Gilmore and R. Gomory, "A Linear Programming Approach to the Cutting Stock Problem," *Operations Research,* Vol. 9, No. 4, pp. 849–859, 1961.
———, "A Linear Programming Approach to the Cutting Stock Problem: Part II," *Operations Research,* Vol. 22, No. 4, pp. 863–888, 1963.

subject to

$$\sum_{k=1}^{n} w_k a_k \leq W$$

$$\sum_{k=1}^{n} d_k a_k \geq 1 + \varepsilon$$

$$a_k \geq 0 \text{ and integer}$$

The second constraint requires that $z_j \left(= \sum_{k=1}^{m} d_k a_k \right)$ be *strictly larger* than c_j $(= 1)$ in order for $\mathbf{P}_j$ to be a promising entering vector (the quantity ε is infinitesimally small).

The solution of the ILP leads to two conclusions:

1. If the solution is feasible, then $\mathbf{P}_j$ must become basic. Use the revised simplex method to determine the leaving vector and the new inverse $\mathbf{B}_j^{-1}$. Repeat step j.
2. If the problem has no feasible solution, then no additional promising $\mathbf{P}_j$ exist and the last basic solution is optimal.

Apply the given algorithm to the trim-loss problem of Example 2.3-9. For convenience, file amplPob7-3.txt provides the AMPL model for the ILP. Although ILP algorithms have not yet been covered (see Chapter 9), the AMPL model is essentially a linear program with the additional requirement that the variables a_i assume integer values—that is,

```
var a{1..3}>=0, integer;
```

Additionally, the statement

```
option solver cplex;
```

must precede the command

```
solve;
```

The only data changes between the successive iterations are the values of the dual values. We can achieve this interactively by using the AMPL `let` command. For example, if the values of d_1 and d_3 change to .5 and .75 respectively (other values remains the same), then we can interactively enter

```
ampl: let d[1]:=.5;
ampl: let d[3]:=.75;
ampl: solve;display a;
```

This means that it is not necessary to hard-code the data in the model at each iteration.

7-4. *Interval programming.* Consider the following LP:

$$\text{Maximize } z = \{\mathbf{CX} | \mathbf{L} \leq \mathbf{AX} \leq \mathbf{U}, \mathbf{X} \geq 0\}$$

where $\mathbf{L}$ and $\mathbf{U}$ are constant column vectors. Define the slack vector such that $\mathbf{AX} + \mathbf{Y} = \mathbf{U}$. Show that this LP is equivalent to

$$\text{Maximize } z = \{\mathbf{CX} | \mathbf{AX} + \mathbf{Y} = \mathbf{U}, 0 \leq \mathbf{Y} \leq \mathbf{U} - \mathbf{L}, \mathbf{X} \geq 0\}$$

Use the proposed procedure to solve the following LP:

$$\text{Minimize } z = 5x_1 - 4x_2 + 6x_3$$

subject to

$$20 \le x_1 + 7x_2 + 3x_3 \le 46$$
$$10 \le 3x_1 - x_2 + x_3 \le 20$$
$$18 \le 2x_1 + 3x_2 - x_3 \le 35$$
$$x_1, x_2, x_3 \ge 0$$

7-5. The optimum solution of the LP in Problem 7-2 is given as $x_1 = \frac{10}{3}$, $x_2 = \frac{4}{3}$, and $z = \frac{38}{3}$. Plot the change in optimum z with θ, given that $x_1 = \frac{10}{3} + \theta$, where θ is unrestricted in sign. Note that $x_1 = \frac{10}{3} + \theta$ tracks x_1 above and below its optimal value.

7-6. Consider the following minimization LP:

$$\text{Minimize } z = (10t - 4)x_1 + (4t - 8)x_2$$

subject to

$$2x_1 + 2x_2 + x_3 = 8$$
$$4x_1 + 2x_2 + x_4 = 6 - 2t$$
$$x_1, x_2, x_3, x_4 \ge 0$$

where $-\infty < t < \infty$. The parametric analysis of the problem yields the following results:

$$-\infty < t \le -5\text{: Optimal basis is } \mathbf{B} = (\mathbf{P}_1, \mathbf{P}_4)$$
$$-5 \le t \le -1\text{: Optimal basis is } \mathbf{B} = (\mathbf{P}_1, \mathbf{P}_2)$$
$$-1 \le t \le 2\text{: Optimal basis is } \mathbf{B} = (\mathbf{P}_2, \mathbf{P}_3)$$

Determine all the critical values of t that may exist for $t \ge 2$.

7-7. Suppose that the optimum linear program is represented as

$$\text{Maximize } z = c_0 - \sum_{j \varepsilon NB} (z_j - c_j)x_j$$

subject to

$$x_i = x_i^* - \sum_{j \varepsilon NB} \alpha_{ij} x_j,\ i = 1, 2, \ldots, m$$
$$\text{all } x_i \text{ and } x_j \ge 0$$

where NB is the set of nonbasic variables. Suppose that for a current basic variable $x_i = x_i$ we impose the restriction $x_i \ge d_i$, where d_i is the smallest integer greater than x_i. Estimate an upper bound on the optimum value of z after the constraint is added to the problem. Repeat the same procedure assuming that the imposed restriction is $x_i \le e_i$, where e_i is the largest integer smaller than x_i.

CHAPTER 8 CASES

8-1.[11] The Warehouzer Company manages three sites of forest land for timber production and reforestation with the respective areas of 100,000, 180,000, and 200,000 acres. The main timber products include three categories: pulpwood, plywood, and sawlogs. Several reforestation alternatives are available for each site, each with its cost, number of rotation years (i.e., number of years from seedling size till harvesting), return from rent, and production output. Table E.23 summarizes this information.

To guarantee sustained future production, each acre of reforestation in each alternative requires that as many acres as years in rotation be assigned to that alternative. The rent column represents the stumpage value per acre.

The goals of Warehouzer are:

1. Annual outputs of pulpwood, plywood, and sawlogs are 200,000, 150,000, and 350,000 cubic meters, respectively.
2. Annual reforestation budget is \$2.5 million.
3. Annual return from land rent is \$100 per acre.

How much land at each site should be assigned to each alternative?

8-2. A charity organization runs a children's shelter. The organization relies on volunteer service from 8:00 A.M. until 2:00 P.M. Volunteers may begin work at the start of any hour

TABLE E.23

		Annual \$/acre			Annual m^3/acre		
Site	Alternative	*Cost*	*Rent*	Rotation yr	*Pulpwood*	*Plywood*	*Sawlogs*
1	*A*1	1000	160	20	12	0	0
	*A*2	800	117	25	10	0	0
	*A*3	1500	140	40	5	6	0
	*A*4	1200	195	15	4	7	0
	*A*5	1300	182	40	3	0	7
	*A*6	1200	180	40	2	0	6
	*A*7	1500	135	50	3	0	5
2	*A*1	1000	102	20	9	0	0
	*A*2	800	55	25	8	0	0
	*A*3	1500	95	40	2	5	0
	*A*4	1200	120	15	3	4	0
	*A*5	1300	100	40	2	0	5
	*A*6	1200	90	40	2	0	4
3	*A*1	1000	60	20	7	0	0
	*A*2	800	48	25	6	4	0
	*A*3	1500	60	40	2	0	4
	*A*4	1200	65	15	2	0	3
	*A*5	1300	35	40	1	0	5

[11]Based on K. Rustagi, *Forest Management Planning for Timber Production: A Goal Programming Approach,* Bulletin No. 89, Yale University, New Haven, 1976.

between 8:00 A.M. and 11:00 A.M. A volunteer works a maximum of 6 hours and a minimum of 2 hours, and no volunteers work during lunch hour between 12:00 noon and 1:00 P.M. The charity has estimated its goal of needed volunteers throughout the day (from 8:00 A.M. to 2:00 P.M., and excluding the lunch hour between 12:00 noon and 1:00 P.M.) as 15, 16, 18, 20, and 16, respectively. The objective is to decide on the number of volunteers that should start at each hour (8:00, 9:00, 10:00, 11:00, and 1:00) such that the given goals are met as much as possible. Formulate and solve the problem as a goal programming model.

CHAPTER 9 CASES

9-1. A development company owns 90 acres of land in a growing metropolitan area, where it intends to construct office buildings and a shopping center. The developed property is rented for 7 years and then sold. The sale price for each building is estimated at 10 times its operating net income in the last year of rental. The company estimates that the project will include a 4.5-million-square-foot shopping center. The master plan calls for constructing three high-rise and four garden office buildings.

The company is faced with a scheduling problem. If a building is completed too early, it may stay vacant; if it is completed too late, potential tenants may be lost to other projects. The demand for office space over the next 7 years based on appropriate market studies is given in Table E.24. Table E.25 lists the proposed capacities of the seven buildings.

TABLE E.24

	Demand (thousands of ft^2)	
Year	*High-rise space*	*Garden space*
1	200	100
2	220	110
3	242	121
4	266	133
5	293	146
6	322	161
7	354	177

TABLE E.25

Garden	Capacity (ft^2)	High-rise buildings	Capacity (ft^2)
1	60,000	1	350,000
2	60,000	2	450,000
3	75,000	3	350,000
4	75,000	—	—

The gross rental income is estimated at $25 per square foot. The operating expenses are $5.75 and $9.75 per square foot for the garden and high-rise buildings, respectively. The associated construction costs are $70 and $105 per square foot, respectively. Both the construction cost and the rental income are estimated to increase at roughly the inflation rate of 4%.

How should the company schedule the construction of the seven buildings?

9-2.[12] In a National Collegiate Athletic Association women's gymnastic meet, competition includes four events: vault, uneven bars, balance beam, and floor exercises. Each team may enter the competition with six gymnasts per event. A gymnast is evaluated on a scale of 1 to 10. Past statistics for the U of A team produce the scores in Table E.26.

The total score for a team is determined by summarizing the top five individual scores for each event. An entrant may participate as a specialist in one event or an "all-rounder" in all four events but not both. A specialist is allowed to compete in at most three events, and at least four of the team participants must be all-rounders. Set up an ILP model that can be used to select the competing team, and find the optimum solution.

9-3.[13] In 1990, approximately 180,000 telemarketing centers employing 2 million individuals were in operation in the United States. In the year 2000, more than 700,000 companies employed approximately 8 million people to telemarket their products. The questions of how many telemarketing centers to employ and where to locate them are of paramount importance.

The ABC company is in the process of deciding on the number of telemarketing centers to employ and their locations. A center may be located in one of several candidate areas selected by the company and may serve (partially or completely) one or more geographical areas. A geographical area is usually identified by one or more (telephone) area codes. ABC's telemarketing concentrates on eight area codes: 501, 918, 316, 417, 314, 816, 502, and 606. Table E.27 provides the candidate locations, their served areas, and the cost of establishing the center. The communication costs per hour between the centers and the area codes are given in Table E.28.

ABC would like to select three or four centers. Where should they be located?

TABLE E.26

	U of A Scores for gymnast					
Event	*1*	*2*	*3*	*4*	*5*	*6*
Vault	6	9	8	8	4	10
Bars	7	9	7	8	9	5
Beam	9	8	10	9	9	8
Floor	6	6	5	9	10	9

[12]Based on P. Ellis and R. Corn, "Using Bivalent Integer Programming to Select Teams for Intercollegiate Women's Gymnastic Competition," *Interfaces,* Vol. 14, No. 3, pp. 41–46, 1984.
[13]Based on T. Spencer, A. Brigandi, D. Dargon, and M. Sheehan, "AT&T's Telemarketing Site Selection System Offers Customer Support," *Interfaces,* Vol. 20, No. 1, pp. 83–96, 1990.

TABLE E.27

Center location	Served area codes	Cost ($)
Dallas, TX	501, 918, 316, 417	500,000
Atlanta, GA	314, 816, 502, 606	800,000
Louisville, KY	918, 316, 417, 314, 816	400,000
Denver, CO	501, 502, 606	900,000
Little Rock, AR	417, 314, 816, 502	300,000
Memphis, TN	606, 501, 316, 417	450,000
St. Louis, MO	816, 502, 606, 314	550,000

TABLE E.28

	Area code							
From \ To	*501*	*918*	*316*	*417*	*314*	*816*	*502*	*606*
Dallas, TX	$14	$35	$29	$32	$25	$13	$14	$20
Atlanta, GA	$18	$18	$22	$18	$26	$23	$12	$15
Louisville, KY	$22	$25	$12	$19	$30	$17	$26	$25
Denver, CO	$24	$30	$19	$14	$12	$16	$18	$30
Little Rock, AR	$19	$20	$23	$16	$23	$11	$28	$12
Memphis, TN	$23	$21	$17	$21	$20	$23	$20	$10
St. Louis, MO	$17	$18	$12	$10	$19	$22	$16	$22

9-4.[14] An electric utility company serving a wide rural area wants to decide on the number and location of Customer-Service Linemen (CSL) centers that will provide responsive service regarding repairs and connections. The company groups its customer base in five clusters according to Table E.29. The company has selected five potential locations for its CSL centers. Table E.30 summarizes the average travel distance in miles from the CSLs to the different clusters. The average speed of the service truck is approximately 45 miles per hour.

The company would like to keep the response time to a customer request to around 90 minutes. How many CSL centers should be in operation?

TABLE E.29

Cluster	1	2	3	4	5
Number of customers	400	500	300	600	700

[14]Based on T. Erkut, Myrdon, and K. Strangway, "Transatlanta Redesigns its Service Delivery Network," *Interfaces,* Vol. 30, No. 2, pp. 54–69, 2000.

TABLE E.30

	CSL Center				
Cluster	*1*	*2*	*3*	*4*	*5*
1	40	100	20	50	30
2	120	90	80	30	70
3	40	50	90	80	40
4	80	70	110	60	120
5	90	100	40	110	90

9-5.[15] In the automobile industry, prototype vehicles are used to test new designs. The building of these vehicles represents a major investment that may exceed $250,000 per prototype. Separate tests are carried out by different groups, each concentrating on checking certain attributes of the new design. For example, possible attributes of a transit vehicle could include body style, engine size, roof height, transmission type, rear closure, gross vehicle weight, and wheel base. To examine a worst-case scenario for high-altitude drivability requires a prototype with highest gross vehicle weight, automatic transmission, and smallest engine. Attributes such as roof height and wheelbase are not important for this type of test.

At the outset, prototypes can be built to meet the individual attributes specified by the tester. For example, if test 1 involves attribute A, and test 2 requires attribute B, two different prototypes can be built: one for A and the second for B. Alternatively, two identical units of prototype (A, B) can be used for the two tests. The advantage is that the production of two identical prototypes is considerably less expensive than building two distinct units. In this case, (A, B) is said to be a *shared* prototype.

In a general situation, let $A_i, i = 1, 2, \ldots, n$, be the set of configurations for attribute i. For example, if attribute 1 is *transmission*, then $A_1 = \{\text{standard, automatic}\}$. A prototype is built using one configuration from each attribute. Thus, if the number of configurations in attribute i is m_i, then the maximum possible number of configurations is $\prod_{i=1}^{n} m_i$. New designs may thus involve thousands of prototypes, and the idea is to make a judicious selection of *shared* prototypes that meet testers' specifications. Let $B_j, j = 1, 2, \ldots, t$, represent the set of configurations requested by tester j. For example, $B_1 = \{\text{V8 engine, standard}\}$. The elements of a set B must thus be a buildable prototype or a subset of it.

TABLE E.31

Attribute	Configurations
Engine	{4 cyl, 6 cyl, 8 cyl}
Transmission	{automatic, standard}
Body style	{4-door, coupe, wagon}

[15]Based on K. Chelst, J. Sidelko, A. Przebienda, J. Lockledge, and D. Mihailidis, "Rightsizing and Management of Prototype Vehicle Testing at Ford Motor Company," *Interfaces,* Vol. 31, No. 1, pp. 91–107, 2001.

TABLE E.32

Tester	Desired configurations
1	{4 cyl, standard}
2	{8 cyl, coupe}
3	{6 cyl, wagon}
4	{8 cyl}
5	{standard, wagon}
6	{6 cyl, automatic}

Based on the given information, how should buildable prototypes be selected to meet the requirements of the testers? Apply the developed model to the situation in Table E.31. The associated testers' requirements are given in Table E.32. [Note: The given situation is oversimplified and obviously can be solved by inspection. In a real situation with thousands of buildable prototypes and tens of requested tests, the solution will not be as obvious.]

9-6.[16] American Express Airlines operates between 8 cities (C1 through C8) with 18 flights (F1 through F18) and 10 flight crews (R1 through R10). Crews normally start from a given base and return to the same base after completing their assignments. Table E.33 provides the daily fight schedules for the airline. The scheduling department is in charge of developing crew pairings that take into account legalities as well as crew preferences. A feasible pairing defines the routes (i.e., flights) a crew can service during the planning period. Table E.34 provides the feasible pairings for the 10 crews. The cost of assigning a crew to a pairing is proportional to the number of flight legs a pairing covers.

TABLE E.33

From city	To city	Flight number
C1	C2	F1
C1	C3	F2
C1	C5	F3
C1	C8	F4
C2	C4	F5
C2	C7	F6
C2	C8	F7
C3	C1	F8
C3	C2	F9
C3	C6	F10
C4	C1	F11
C4	C8	F12
C5	C2	F13
C5	C7	F14
C6	C4	F15
C6	C1	F16
C7	C4	F17
C8	C3	F18

[16]Based on G. Yu, M. Arguello, G. Song, S. McCowan, and A. White, "A New Era for Recovery at Continental Airlines," *Interfaces,* Vol. 3, No. 1, pp. 5–22, 2003.

TABLE E.34

Crew	Feasible pairings
1	(C3,C6,C4,C8,C3), (C3, C2,C8,C3)
2	(C1,C5,C7,C4,C1)
3	(C4,C8,C3,C2,C4), (C4,C1,C5,C7,C4)
4	(C1,C8,C3,C6,C4,C1), (C1,C5,C2,C1)
5	(C2,C4,C8,C3,C2), (C2,C4,C8,C3,C1,C2), (C2,C7,C4,C1,C2)
6	(C8,C3,C1,C8)
7	(C5,C2,C8,C3,C1,C5), (C5,C7,C4,C8,C3,C1,C5)
8	(C6,C1,C3,C6), (C6,C4,C1,C5,C7,C4,C8,C3,C6), (C6,C4,C8,C3,C6)
9	(C7,C4,C2,C7), (C7,C4,C8,C3,C2,C7)
10	(C1,C3,C6,C1), (C1,C2,C8,C3,C1), (C1,C8,C3,C1)

Because the pairings are developed to satisfy the crew preferences as well as FAA regulations, the pairings proposed by the scheduling department may not produce a feasible solution that covers all the flights and engages all the crews. The objective then is to assign crew pairings in a manner that will eliminate infeasibilities as much as possible. The assumption is that if the developed solution is infeasible, then the scheduling department should either propose additional feasible pairings or seek the service of reserve crews.

Develop a model that can be used to evaluate the pairings proposed by the scheduling department and interpret the solution.

9-7.[17] The core manufacturing flow for microelectronic parts starts with *wafers* (CD-like round thin pieces of silicon) on which thousands of circuits are etched. A completed wafer is then cut into small rectangular parts, called *devices*, placed on a substrate, and packaged to create a module. After testing, the devices are found to fall in different categories, each with distinct circuits. Given that N is the number of devices cut from a wafer with n categories, the number of units *binned* into category j is estimated at r_jN, where $r_1 + r_2 + \cdots + r_n = 1, r_j \geq 0$, for all j. Produced devices may be used interchangeably in the production of a module, so that one unit of device i or device j may be used to produce one unit of module k. Interchangeability of devices is a function of the specification of the module. Given the binning ratios r_j, how many wafers should be produced to satisfy a specific demand for the modules? How should the produced devices be allocated to the modules?

Test the developed model for a specific situation with 5 devices and 3 modules using the data in Tables E.35 and E.36.

TABLE E.35

Device	1	2	3	4	5
Binning ratio	.21	.19	.1	.3	.2
Initial inventory	10	4	8	0	3

[17]Based on P. Lyon, R. Milne, R. Orzell, and R. Rice, “Matching Assets with Demand in Supply-Chain Management at IBM Microelectronics,” *Interfaces*, Vol. 31, No. 1, pp. 108–124, 2001.

TABLE E.36

Module	Demand (units)	Interchangeable devices
1	20	2, 3, or 5
2	30	1, 3, or 5
3	45	4, or 5

9-8.[18] In days past, banks used to clear checks against a customer's account in the random order in which the checks were received. Nowadays, and with the advent of modern data processing capabilities, some banks are legally allowed to sequence the daily debiting process in a manner that garners higher return fees for insufficient funds. For example, suppose that a bank account has a balance of $1000 and that in a specific day four successive checks are received in the amounts $100, $100, $100, and $1000. If these checks are debited in their order of receipt, only one check ($1000) should be returned for not-sufficient funds (NSF). In this case, the customer is responsible for one NSF charge (of about $20). If, on the other hand, the checks are debited in the order $1000, $100, $100, and $100, three NSF checks will result, and the bank collects three NSF charges. From this example, it appears that a bank can maximize its NSF charges by using a high-low sequence that debits the higher checks first. This is not true, in general. For example, consider the high-low sequence of $900, $675, $525, $200, $100, $75, and $25 against an account balance of $1200. In this case, the checks $900, $200, and $100 are cleared and the remaining four checks carry NSF charges. Actually, the bank could collect one extra NSF if it skipped the $900 check and cleared the $675 and $525 checks (= $1200) first.

(a) Develop a model that will allow banks to process the daily checks in a manner that guarantees the collection of maximum NSF charges, and apply the model to the given data.

(b) Ethically, one should expect banks to offer the best service to customers by minimizing the NSF charges. How should the checks be processed in this case?

9-9. Consider Case 3-3 (Chapter 3). For some bidders an awarded quantity is acceptable only if it satisfies the specific minimum requirement given in Table E.37. A successful

TABLE E.37

	Minimum quantity required by bidders 1-8 of line items 1-6 (in 1000 barrels)							
Line item	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
1	10	13	10	25	18	14	20	14
2	14	11	11	20	17	16	18	14
3	20	15	20	10	16	16	17	17
4	11	17	15	6	20	16	17	8
5	15	29	18	12	14	10	15	10
6	18	20	19	22	18	8	19	15

[18]Based on A. Apte, U. Apte, R. Beatty, I. Sarkar, and J. Semple, "The Impact of Check Sequencing on NSF (Not-Sufficient Funds) Fees," *Interfaces*, Vol. 34, No. 2, pp. 97–105, 2004.

TABLE E.38

Project	1	2	3	4	5	6	7	8
Cost ($\$10^6$)	10	2	24	5	15	12	7	9

TABLE E.39

	Travel time to project locations in hours by manager				
Project	*a*	*b*	*c*	*d*	*e*
1	2	5	3	1	6
2	5	4	2	5	3
3	4	1	3	2	2
4	5	3	6	3	4
5	1	4	5	6	1
6	2	4	6	2	3
7	6	7	2	3	3
8	4	2	1	5	4

bidder must receive *at least* the minimum requirement (but within the 20% limit specified by law). Else no award is made to the bidder.

How can this task be accomplished?

9-10.[19] A construction company has been awarded contracts for 8 projects located in different geographical locations around the United States. Each project is administered by one of the company's 5 managers. The managers are stationed in different home bases around the country, and their travel times to different project locations vary. High-cost projects are administratively more demanding. To be equitable, the company assigns managers to the projects depending on both the size of the project and also the proximity of the manager's home base to the location of the project. Table E.38 gives the estimated costs of the projects (in millions of dollars). The travel times are given in Table E.39. How should the managers be assigned to the projects? [*Hint*: Base assignments on project intensity, defined here as (travel time in hours $+ 1) \times 6 \times \log($project cost in million \$$) + 1$. The expression is a well-known measure of project intensity in construction.]

CHAPTER 10 CASE

10-1. A company reviews the status of heavy equipment at the end of each year, and a decision is made either to keep the equipment an extra year or to replace it. However, equipment that has been in service for 3 years must be replaced. The company wishes to develop a replacement policy for its fleet over the next 10 years. Table E.40 provides the pertinent data. The equipment is new at the start of year 1.

[19]Based on L. LeBlanc, D. Randels, Jr., and T. K. Swann, "Heery International's Spreadsheet Optimizations Model for Assigning Managers to Construction Projects," *Interfaces*, Vol. 30, No. 6, pp. 95–106, 2000.

TABLE E.40

Year	Purchase price ($)	Maintenance cost ($)			Salvage value ($)		
		0	*1*	*2*	*1*	*2*	*3*
1	10,000	200	500	600	9,000	7,000	5,000
2	12,000	250	600	680	11,000	9,500	8,000
3	13,000	280	550	600	12,000	11,000	10,000
4	13,500	320	650	700	12,000	11,500	11,000
5	13,800	350	590	630	12,000	11,800	11,200
6	14,200	390	620	700	12,500	12,000	11,200
7	14,800	410	600	620	13,500	12,900	11,900
8	15,200	430	670	700	14,000	13,200	12,000
9	15,500	450	700	730	15,500	14,500	13,800
10	16,000	500	710	720	15,800	15,000	14,500

CHAPTER 11 CASES

11-1. The distribution center of the retailer Walmark Stores engages on a daily basis in buying many staple, nonfashionable inventory items. Steady demand for the various items comes from the numerous stores Walmark owns. In the past, decisions regarding *how much* and *when* to order were relegated to the buyers, whose main purpose was to acquire the items in sufficiently large quantities to guarantee the low purchase prices. This policy was carried out without conscious concern about the inventory status of the items. Indeed, decisions regarding how much to buy were based on the annual dollar usage of the item at the distribution center level. For example, if an item was purchased for $25 a unit and consumed at the rate of 10,000 units a year, then its annual dollar usage is estimated at $250,000. The main guideline the buyers used was that the higher the annual dollar usage of an item, the higher should be its stock level in the distribution center. This guideline translated into expressing the amount of inventory that must be kept on hand at the distribution center as the period between replenishment. For example, a buyer might purchase a prespecified amount of an item every three months.

To exercise better inventory control, Walmark decided to enlist the help of an operations research consultant. After studying the situation, the consultant concluded that the consumption rate of most items in the distribution center was, for all practical purposes, constant and that Walmark operated under the general policy of not allowing shortages. The study further indicated that the inventory-holding cost for all the items under consideration was a constant percentage of the unit purchase price. Furthermore, the fixed cost a buyer incured with each purchase was the same regardless of the item involved. Armed with this information, the consultant was able to develop a single curve for any single item that related the annual dollar usage to the average time between replenishment. This curve was then used to decide on which items currently were overstocked or understocked. How did the analyst do it?

11-2. A company manufactures a final product that requires the use of a single component. The company purchases the component from an outside supplier. The demand rate for the final product is constant at about 20 units per week. Each unit of the final product uses 2 units of the purchased component. Table E.41 inventory data are available.

TABLE E.41

	Component	Product
Setup cost per order ($)	80	100
Unit holding cost per week ($)	2	5
Lead time (wk)	2	3

TABLE E.42

	Yr				
Mo	*1*	*2*	*3*	*4*	*5*
Jan.	10	11	10	12	11
Feb.	50	52	60	50	55
March	8	10	9	15	10
April	99	100	105	110	120
May	120	100	110	115	110
June	100	105	103	90	100
July	130	129	125	130	130
Aug.	70	80	75	75	78
Sept.	50	52	55	54	51
Oct.	120	130	140	160	180
Nov.	210	230	250	280	300
Dec.	40	46	42	41	43

Unfilled demand of the final product is backlogged and costs about $8 per lost unit per week. Shortage in the purchased component is not expected to occur. Devise an ordering policy for the purchase of the component and the production of the final product.

11-3. A company deals with a seasonal item, for which the monthly demand fluctuates appreciably. Table E.42 provides demand data (in number of units). Because of the fluctuations in demand, the inventory control manager has chosen a policy that orders the item quarterly on January 1, April 1, July 1, and October 1. The order size covers the demand for each quarter. The lead time between placing an order and receiving it is 3 months. Estimates for the current year's demand are taken equal to the demand for year 5, plus an additional 10% safety factor.

A new staff member believes that a better policy can be determined by using the economic order quantity based on the average monthly demand for the year. Fluctuations in demand can be "smoothed" out by placing orders to cover the demands for consecutive months, with the size of each order approximately equal to the economic lot size. Unlike the manager, the new staff member believes that the estimates for next year's demand should be based on the average of years 4 and 5.

The company bases its inventory computations on a holding cost of $.50 per unit inventory per month. A setup cost of $55 is incurred when a new order is placed.

Suggest an inventory policy for the company.

CHAPTER 13 CASES

13-1.[20] A shop manager is considering three alternatives to an existing milling machine.

(a) Retrofit the existing mill with a power feed (PF).

(b) Buy a new mill with a computer-aided design (CAD) feature.

(c) Replace the mill with a machining center (MC).

The three alternatives are evaluated based on two criteria: monetary and performance. Table E.43 provides the pertinent data. The manager surmises that the monetary criterion is $1\frac{1}{2}$ times as important as the performance criterion. Additionally, the production rate is twice as important as the setup time, and 3 times as important as the scrap. The setup time is regarded as 4 times as important as the scrap. As for the monetary criterion, the manager estimates that the maintenance and training costs are of equal importance, and the initial cost is twice as important as either of these two costs.

Analyze the situation, and make an appropriate recommendation.

13-2.[21] A company operates a catalog sales operation encompassing more than 200,000 items stocked in many regional warehouses. In the past, the company considered it essential to keep accurate records of the actual inventory in each warehouse. As a result, a full inventory count was ordered every year—an intense and unwelcome activity that was done grudgingly by all warehouses. The company followed each count by an audit that sampled about 100 items per warehouse to check the quality of the logistical operation in each region. The result of the audit indicated that, on the average, only 64% of the items in each warehouse matched the actual inventory, which was unacceptable. To remedy the situation, the company ordered more frequent counts of the expensive and fast-moving items. A system analyst was assigned the task of setting up procedures for targeting these items.

Instead of responding directly to the company's request for identifying the target items, the system analyst decided to identify the cause of the problem. The analyst ended up changing the goal of the study from "How can we increase the frequency of inventory counts?" to "How can we increase the accuracy of inventory counts?" The

TABLE E.43

Criterion	PF	CAD	MC
Monetary			
Initial cost ($)	12,000	25,000	120,000
Maintenance cost ($)	2000	4000	15,000
Training cost ($)	3000	8000	20,000
Performance			
Production rate (units/day)	8	14	40
Setup time (min)	30	20	3
Scrap (lb/day)	440	165	44

[20] Based on S. Weber, "A Modified Analytic Hierarchy Process for Automated Manufacturing Decisions," *Interfaces*, Vol. 23, No. 4, pp. 75–84, 1993.

[21] Based on I. Millet, "A Novena to Saint Anthony, or How to Find Inventory by Not Looking," *Interfaces*, Vol. 24, No. 2, pp. 69–75, 1994.

study led to the following analysis: Given that the proportion of accurately counted items in a warehouse is p, it is reasonable to assume that there is a 95% chance that an item that was counted correctly in the first place will again be recounted correctly in a subsequent recount. For the proportion $1 - p$ that was not counted correctly in the first round, the chance of a correct recount is 80%. Using this information, the analyst developed a decision tree to graph a break-even chart that compared the count accuracy in the first and second rounds. The end result was that the warehouses that had an accuracy level above the break-even threshold were not required to recount inventory. The surprising result of the proposed solution was a zealous effort on the part of each warehouse to get the count right the first time around, with a resounding across-the-board improvement in count accuracy in all the warehouses.

How did the analyst convince management of the viability of the proposed threshold for recounting?

13-3.[22] In the airline industry, working hours are ruled by agreements with the unions. In particular, the maximum length of tour of duty may be limited to 16 hours for Boeing-747 flights and 14 hours for Boeing-707. If these limits are exceeded because of unexpected delays, the crew must be replaced by a fresh one. The airlines maintain reserve crews for such eventualities. The average annual cost of a reserve crew member is estimated at $30,000. Conversely, an overnight delay resulting from the unavailability of a reserve crew could cost as much as $50,000 for each delay. A crew member is on call 12 consecutive hours a day for 4 days of the week and may not be called on during the remaining 3 days of the week. A B-747 flight may also be served by two B-707 crews.

Table E.44 summarizes the callout probabilities for reserve crews based on 3-year historical data. As an illustration, the data indicate that for 14-hour trips, the probability of a callout is .014 for B-747 and .072 for B707. Table E.45 provides a typical peak-day schedule. The present policy for reserve crews calls for using two (seven-member) crews between 5:00 and 11:00, four between 11:00 and 17:00, and two between 17:00 and 23:00.

Evaluate the effectiveness of the present reserve crew policy. Specifically, is the present reserve crew size too large, too small, or just right?

13-4.[23] During the well-publicized 1982 trial of John Hinkley, accused of attempting to assassinate U.S. President Ronald Reagan, the defense attorney wanted to introduce Hinkley's

TABLE E.44

		Callout probability	
Trip category	Trip hr	*B-747*	*B-707*
1	14.0	.014	.072
2	13.0	.0	.019
3	12.5	.0	.006
4	12.0	.016	.006
5	11.5	.003	.003
6	11.0	.002	.003

[22]Based on A. Gaballa, "Planning Callout Reserves for Aircraft Delays," *Interfaces*, Vol. 9, No. 2, Part 2, pp. 78–86, 1979.
[23]Based on A. Barnett, I. Greenberg, and R. Machol, "Hinckley and the Chemical Bath," *Interfaces*, Vol 14, No. 4, pp. 48–52, 1984.

TABLE E.45

Time of day	Aircraft	Trip category
8:00	707	3
9:00	707	6
	707	2
10:00	707	3
11:00	707	2
	707	4
15:00	747	6
16:00	747	4
19:00	747	1

CAT scan results as evidence that his client was mentally ill. Hinkley's CAT scan did show brain atrophy. Expert testimony during the trial stipulated that 30% of individuals diagnosed with schizophrenia had brain atrophy, as opposed to only 2% of those who were not schizophrenic. Statistics show that approximately 1.5% of the U.S. population suffer from schizophrenia.

Analyze the situation from the standpoint of the impact of introducing CAT scan results as evidence on the outcome of the trial.

13-5.[24] An instructor wants to estimate the probability that students in his junior-senior class have ever cheated in a test during their tenure at the university. To obtain unbiased (truthful) answers from the students, each student is asked to toss a coin privately to answer a decoy question if the outcome is Heads or a real question if the outcome is Tails. The real question is "Did you ever cheat in a test?" and the decoy question is "Are you a graduating senior?" Each student answers "yes" or "no" on a sheet of paper, and the sheets are then collected and tallied by the instructor. Privacy is guaranteed because no one but the individual student knows which question was answered. Of the 35 students participating in the experiment, 20 are graduating seniors. The tallied results of the experiment show 18 yes and 17 no answers. Use this information to estimate the probability that a student in the designated class has ever cheated in a test.

CHAPTER 14 CASES

14-1.[25] A telephone company operates *telephone centers* that provide residential services to customers in their respective domains. There are more than 60 telephone models to choose from. Currently, each phone center holds from 15 to 75 days of stock. The management considers such stock levels to be excessive because they are replenished on a daily basis from a central warehouse. At the same time, the management wants to ensure that sufficient stock is maintained at the telephone centers to provide a service level of 95% for the customers. The team studying the problem started by collecting pertinent data. The team's objective was to establish an optimal stock level

[24]Based on R. Sheaffer, J. Witmer, A. Watkins, and M. Gnanadesikan, *Activity-Based Statistics*, Springer-Verlag, New York, 1996, p. 133.

[25]Based on R. Cohen, and F. Dunford, "Forecasting for Inventory Control: An Example of When 'Simple' Means 'Better'", *Interfaces*, Vol. 16, No. 6, pp. 95–99, 1986.

TABLE E.46

Sets issued	0	1	2	3	4
Frequency	189	89	20	4	1

for each telephone model. Table E.46 shows the number of sets issued in a day of the green, desktop, rotary-dial model (Green 500). Similar tables were developed for all the models.

The desired cost parameters needed to determine the optimal stock level for each telephone model are difficult to estimate, so traditional inventory models cannot be applied. Based on the observation that both regression and time series analyses failed to detect appreciable trends in demand, the team has decided to use a more basic approach for determining appropriate stock levels for the different phone models.

Suggest a method for determining adequate stock levels for the different models. State all the assumptions made to reach a decision.

14-2.[26] The inventory manager of a small retail stores places orders for items to take advantage of special offers or to combine orders received from one supplier. The result is that both the order quantity and the cycle length (interval between successive orders) become essentially random. Moreover, because the manager's policy is driven mostly by noninventory considerations, the order quantity and cycle length can be considered independent, in the sense that shorter cycle lengths do not necessarily mean smaller order quantities and vice versa.

Table E.47 provides typical data for three items that were ordered simultaneously. The data show that both the order quantity and the cycle length are random. Moreover, a cursory look at the entries of the table reveals the lack of correlation between the order quantity and the cycle length.

A goodness-of-fit analysis of the complete set of data (see Chapter 12) reveals that the distribution of the demand rates (order quantity divided by cycle length) for the three items follows a Weibull distribution, $f(r)$, of the form

$$f(r) = \frac{2r}{\alpha} e^{-r^2/\alpha}, \; r \geq 0$$

where r is the demand rate for the item. Similarly, the analysis shows that the distribution of the *reciprocal* of the cycle length, $s(x)$, is exponential of the form

$$s(x) = \beta e^{-\beta(x-a)}, \; x \geq a$$

where a is the minimum value assumed by x.

The determination of the optimal order quantity is based on the maximization of the expected profit per month,which is defined as

$$\text{Expected profit} = \int \left\{ \frac{1}{t} \int u(q, r, t) f(r)\, dr \right\} g(t)\, dt$$

$$= \int \left\{ x \int u\left(q, r, \frac{1}{x}\right) f(r)\, dr \right\} s(x)\, dx$$

[26]Based on A. Holt, "Multi-Item Inventory Control for Fluctuating Reorder Intervals," *Interfaces*, Vol. 16, No. 3, pp. 60–67, 1986.

TABLE E.47

Cycle length (mo)	Order quantity (units)		
	Item 1	*Item 2*	*Item 3*
2.3	10	8	1
2.6	4	6	0
4	1	4	2
2.0	8	6	2
1.2	7	0	2
1.4	0	10	1
1.7	1	2	0
1.3	0	5	2
1.1	9	4	3
1.8	4	6	2
1.6	2	0	0
.5	5	3	1
2.1	10	7	2
2.3	4	12	4
2.4	8	9	3
2.1	10	8	5
2.2	9	13	2
1.8	12	8	4
.7	6	4	2
2.1	5	4	0

where t and $g(t)$ are the cycle length and its density function. The profit function $u(q, r, t)$ is based on p, the net unit profit for the item, h, the holding cost per unit per month, and K, the fixed order cost.

(a) Use the data for the three items to determine the probability density function for each demand rate.

(b) Use the data for the cycle length to determine $s(x)$.

(c) Develop the mathematical expression for $u(q, r, t)$.

Determine the optimal order quantity for the three items, given the following cost data: $p_1 = \$100$, $p_2 = \$150$, $p_3 = \$125$, $h_1 = \$2$, $h_2 = \$1.20$, $h_3 = \$1.65$, and $K = \$30$.

CHAPTER 15 CASES

15-1.[27] The Bank of Elkins currently operates a traditional drive-in station and two "robo" lanes that connect to the inside of the bank through a pneumatic cartridge. The bank would like to expand the existing facilities so that an arriving car would complete its business in no more than 4 minutes, on the average. This time limit was based on psychological studies that show that customers base their impatience on the movement of the minute hand between two marks, which on most watches represents five minutes. To collect the necessary data, the team observed the operation of the existing tellers. After

[27]Based on B. Foote, "A Queuing Case Study in Drive-In Banking," *Interfaces*, Vol. 6, No. 4., pp. 31–37, 1976.

studying the system for a while, a member of the team noticed that there was a marked difference between the time a customer spent in the drive-in lane and the time the teller spent carrying out the necessary bank transactions. In fact, the time a car spent in the system consisted of (1) realizing the car in front had moved, (2) moving to the teller window, (3) giving the teller instructions, (4) teller taking action, and (5) moving out. During the first second and fifth components of this time period, the teller was involuntarily idle. Indeed, during each cycle, the teller was busy serving the customer only 40% of the time. Based on this information, the team discovered that there was room for reducing the operating cost of the present system.

What was the team's suggestion for improving the existing drive-in operation? Discuss all the implications of the suggestion.

15-2. A state-run child abuse center operates from 9:00 A.M. to 9:00 P.M. daily. Calls reporting cases of child abuse arrive in a completely random fashion, as should be expected. Table E.48 gives the number of calls recorded on an hourly basis over a period of 7 days. The table does not include lost calls resulting from the caller receiving a busy signal. Each received call lasts randomly for up to 12 minutes with an average of 7 minutes. Past records show that the center has been experiencing a 15% annual rate of increase in telephone calls.

The center would like to determine the number of telephone lines that must be installed to provide adequate service now and in the future. In particular, special attention is given to reducing the adverse effect of a caller's receiving a busy signal.

15-3. A manufacturing company employs three trucks to transport materials among six departments. Truck users have been demanding that a fourth truck be added to the fleet to alleviate the problem of excessive delays. The trucks do not have a home station from which they can be called. Instead, management considers it more efficient to keep the trucks in continuous motion about the factory. A department requesting the use of a truck must await its arrival in the vicinity. If the truck is available, it will respond to the call. Otherwise, the department must await the appearance of another truck. Table E.49 gives the frequency of the number of calls per hour. The service time for each department

TABLE E.48

Starting hour	Total no. of calls for day						
	1	*2*	*3*	*4*	*5*	*6*	*7*
9:00	4	6	8	4	5	3	4
10:00	6	5	5	3	6	4	7
11:00	3	9	6	8	4	7	5
12:00	8	11	10	5	15	12	9
13:00	10	9	8	7	10	16	6
14:00	8	6	10	12	12	11	10
15:00	10	9	12	4	10	6	8
16:00	8	6	9	14	12	10	7
17:00	5	10	10	8	10	10	9
18:00	5	4	6	5	6	7	5
19:00	3	4	6	2	3	4	5
20:00	4	3	6	2	2	3	4
21:00	1	2	2	3	3	5	3

TABLE E.49

Calls/hr	Frequency
0	30
1	90
2	99
3	102
4	120
5	100
6	60
7	47
8	30
9	20
10	12
11	10
12	4

(in minutes) is approximately the same. Table E.50 summarizes a typical service time histogram for one of the departments.

Analyze the effectiveness of the present operation.

15-4. A young industrial engineer, Jon Micks, was recently hired by Metalco. The company owns a 30-machine shop and has hired 6 repairpersons to take care of repairs. The shop operates for one shift that starts at 8:00 A.M. and ends at 4:00 P.M. Jon's first assignment was to study the effectiveness of the repair service in the shop. To that end, he collected the data in Table E.51 from the repair log for three randomly selected machines. Additionally, by checking the repair records for five randomly selected days, Jon was able to compile the data in Table E.52 representing the number of broken machines (including those being repaired) at the beginning of every hour of the work day.

Jon has a meeting with his supervisor, Becky Steele, regarding the data he has collected. He states that he is confident that the breakdown/repair process in the shop is totally random and that it is safe to assume that the situation can be described as a Poisson queue. Becky confirms that her long experience in the shop indicates that the situation is indeed totally random. Based on this observation, she examines Jon's data, and after making some computations, she announces to Jon that there is something wrong with the data. How did Becky reach that conclusion?

TABLE E.50

Service time, t	Frequency
$0 \le t < 10$	61
$10 \le t < 20$	34
$20 \le t < 30$	15
$30 \le t < 40$	5
$40 \le t < 50$	8
$50 \le t < 60$	4
$60 \le t < 70$	4
$70 \le t < 80$	3
$80 \le t < 90$	2
$90 \le t < 100$	2

TABLE E.51

Machine 5		Machine 18		Machine 23	
Failure hour	*Repair hour*	*Failure hour*	*Repair hour*	*Failure hour*	*Repair hour*
8:05	8:15	8:01	8:09	8:45	8:58
10:02	10:14	9:10	9:18	9:55	10:06
10:59	11:09	11:03	11:16	10:58	11:08
12:22	12:35	12:58	13:06	12:21	12:32
14:12	14:22	13:49	13:58	12:59	13:07
15:09	15:21	14:30	14:43	14:32	14:43
15:33	15:42	14:57	15:09	15:09	15:17
15:48	15:59	15:32	15:42	15:50	16:00

TABLE E.52

	Total number of broken machines at the hour of							
Date	*8:00*	*9:00*	*10:00*	*11:00*	*12:00*	*13:00*	*14:00*	*15:00*
10/2	6	6	9	6	8	8	7	7
10/29	9	8	5	9	5	5	6	8
11/4	6	6	5	7	7	8	6	5
12/1	9	5	9	7	5	7	5	5
1/19	6	5	8	5	9	8	8	6

15-5. The Yellow Cab Company owns four taxis. The taxi service operates for 10 hours daily. Calls arrive at the dispatching office according to a Poisson distribution with amean of 20 calls per hour. The length of the ride is known to be exponential with mean 11.5 minutes. Because of the high demand for cabs, Yellow limits the waiting list at the dispatching office to 16 customers. Once the limit is reached, future customers are advised to seek service elsewhere because of the expected long wait.

The company manager, Kyle Yellowstone, is afraid that he may be losing too much business and thus would like to consider increasing the size of his fleet. Yellowstone estimates that the average income per ride is about $5. He also estimates that a new cab can be purchased for $18,000. A new cab is kept in service for 5 years and then sold for $3500. The annual cost of maintaining and operating a taxi is $20,000 a year. Can Mr. Yellowstone justify increasing the size of his fleet, and if so, by how many? For the analysis, assume a 10% annual interest rate.

CHAPTER 20 CASES

20-1.[28] The department of industrial engineering at U of A has 3 faculty members and offers a total 5 courses in a two-semester academic year. The department has 2 graduate stu-

[28]Based on J. Dyer and J. Mulvey., "An Integrated Information/Optimization for Academic Planning," *Management Science,* Vol. 22, No. 12, pp.582–600, 1976.

dents who can teach courses C1 and C3, but only as a last resort if the regular faculty cannot teach these classes. A student may not teach more than one course per semester. Tables E.53 and E.54 specify each professor's preferences for teaching certain courses and the number of sections per semester that must be taught of each course.

Develop a model that can be used to assign faculty (and graduate students, if necessary) to the designated classes.

CHAPTER 21 CASE

21-1. A published argument advocates that the recent rise in the mean score of the Scholastic Aptitude Test (SAT) for high school students in the United States be attributed to demographic reasons rather than to improvement in teaching methods. Specifically, the argument states that the decrease in the number of children per family has created environments in which kids are interacting more frequently with adults (namely, their parents), which increases their intellectual skills. Conversely, children of large families are not as "privileged" intellectually because of the immature influence of their siblings.

What is your opinion regarding the development of a predictive regression equation for the SAT scores based on this argument?

TABLE E.53

		Number of sections per semester	
Course	Number of sections per academic year	*Fall*	*Spring*
C1	2	1	1
C2	2	1 or 2	1
C3	2	1 or 2	1 or 2
C4	1	1	0
C5	1	0	1

TABLE E.54

		Teaching load per semester		
Professor	Teaching load per academic year	*Fall*	*Spring*	Order of preference for courses
P1	1	0 or 1	0 or 1	$C1 > C2 > C5$
P2	3	1 or 2	1 or 2	$C1 > C3 > C2 > C4$
P3	2	0, 1, or 2	0 or 1	$C5 > C4 > C3 > C1$

CHAPTER 22 CASE

22-1. UPPS uses trucks to deliver orders to customers. The company wants to develop a replacement policy for its fleet over the next 5 years. The annual operating cost of a new truck is normally distributed with mean \$300 and standard deviation \$50. The mean and standard deviation of the operating cost increases by 10% a year thereafter. The current price of a new truck is \$20,000 and is expected to increase by 12% a year. Because of the extensive use of the truck, there is a chance that it might break down irreparably at any time. The trade-in value of a truck depends on whether it is broken or in working order. At the start of year 6, the truck is salvaged, and its salvage value again depends on its condition (broken or in working order). Table E.55 provides the data of the situation as a function of the age of the truck.

If the truck is in working condition, its trade-in value after 1 year of operation is 70% of the purchase price and decreases by 15% a year thereafter. The trade-in value of the truck is halved if it is broken. The salvage value of the truck at the start of year 6 is \$200 if it is in working condition and \$50 if it is broken. Develop the optimal replacement policy for the truck.

TABLE E.55

Truck age (yr)	0	1	2	3	4	5	6
Probability of breakdown	.01	.05	.10	.16	.25	.40	.60