2 Why should a service organization worry about being world-class if it does not compete outside its own national border? What impact does the Internet have on this?
3 What are the major priorities associated with operations strategy? How has their relationship to one another changed over the years?
4 For each priority in question 3, describe the unique characteristics of the market niche with which it is most compatible.
5 A few years ago, the dollar showed relative weakness with respect to foreign currencies such as the yen, euro, and pound. This stimulated exports. Why would long-term reliance on a lower-valued dollar be at best a short-term solution to the competitiveness problem?
6 In your opinion, do business schools have competitive priorities?
7 Why does the "proper" operations strategy keep changing for companies that are world-class competitors?
8 What is meant by the expressions *order winners* and *order qualifiers*? What was the order winner(s) for your last major purchase of a product or service?
9 What do we mean when we say productivity is a "relative" measure?

PROBLEMS*

1. $(2.36 + 1.80 + 1.75 + 2.34)/4 = 2.06$

1 As operations manager, you are concerned about being able to meet sales requirements in the coming months. You have just been given the following production report.

	JAN	FEB	MAR	APR
Units produced	2300	1800	2800	3000
Hours per machine	325	200	400	320
Number of machines	3	5	4	4

Find the average monthly productivity (units per hour).

2. $(1217 \times 1700)/(46672 \times 12) = 3.69$

2 Sailmaster makes high-performance sails for competitive windsurfers. Below is information about the inputs and outputs for one model, the Windy 2000.

Units sold	1,217
Sale price each	$1,700
Total labor hours	46,672
Wage rate	$12/hour
Total materials	$60,000
Total energy	$4,000

Calculate the productivity in **sales revenue/labor expense**.

3. $(50000 \times 3.5)/((620 \times 7.50) + 30000 + 15350) = 3.5$

3 *Acme Corporation* received the data below for its rodent cage production unit. Find the **total** productivity.

OUTPUT	INPUT	
50,000 cages	Production time	620 labor hours
Sales price: $3.50 per unit	Wages	$7.50 per hour
	Raw materials (total cost)	$30,000
	Component parts (total cost)	$15,350

4. | PRODUCTIVITY | (HOURS) |
|---|---|
| Deluxe car | 0.20 |
| Limited car | 0.20 |
| PRODUCTIVITY | (DOLLARS) |
| Deluxe car | 133.33 |
| Limited car | 135.71 |

4 Two types of cars (Deluxe and Limited) were produced by a car manufacturer in 2008. Quantities sold, price per unit, and labor hours follow. What is the labor productivity for each car? Explain the problem(s) associated with the labor productivity.

	QUANTITY	$/UNIT
Deluxe car	4,000 units sold	$8,000/car
Limited car	6,000 units sold	$9,500/car
Labor, Deluxe	20,000 hours	$12/hour
Labor, Limited	30,000 hours	$14/hour

*Special thanks to Bill Ruck of Arizona State University for the problems in this section.

5 A U.S. manufacturing company operating a subsidiary in an LDC (less developed country) shows the following results:

	U.S.	LDC
Sales (units)	100,000	20,000
Labor (hours)	20,000	15,000
Raw materials (currency)	$20,000	FC 20,000
Capital equipment (hours)	60,000	5,000

a. Calculate partial labor and capital productivity figures for the parent and subsidiary. Do the results seem misleading?

b. Compute the multifactor productivity figures for labor and capital together. Are the results better?

c. Calculate raw material productivity figures (units/$ where $1 = FC 10). Explain why these figures might be greater in the subsidiary.

5. *a.* Yes:

U.S.	LDC
5.00	1.33
1.67	4.00

b. Yes:

U.S.	LDC
1.25	1.00

c.

U.S.	LDC
5	10

6 Various financial data for 2007 and 2008 follow. Calculate the total productivity measure and the partial measures for labor, capital, and raw materials for this company for both years. What do these measures tell you about this company?

		2007	2008
Output:	Sales	$200,000	$220,000
Input:	Labor	30,000	40,000
	Raw materials	35,000	45,000
	Energy	5,000	6,000
	Capital	50,000	50,000
	Other	2,000	3,000

6.

	2007	2008
Total productivity	1.64	1.53
Partial labor	6.67	5.50
Partial raw materials	5.71	4.89
Partial capital	4.00	4.40

7 An electronics company makes communications devices for military contracts. The company just completed two contracts. The navy contract was for 2,300 devices and took 25 workers two weeks (40 hours per week) to complete. The army contract was for 5,500 devices that were produced by 35 workers in three weeks. On which contract were the workers more productive?

7. Army (1.31)

8 A retail store had sales of $45,000 in April and $56,000 in May. The store employs eight full-time workers who work a 40-hour week. In April the store also had seven part-time workers at 10 hours per week, and in May the store had nine part-timers at 15 hours per week (assume four weeks in each month). Using sales dollars as the measure of output, what is the percentage change in productivity from April to May?

8. 6.67% increase

9 A parcel delivery company delivered 103,000 packages in 2007, when its average employment was 84 drivers. In 2008 the firm handled 112,000 deliveries with 96 drivers. What was the percentage change in productivity from 2007 to 2008?

9. 4.85% decrease

10 A fast-food restaurant serves hamburgers, cheeseburgers, and chicken sandwiches. The restaurant counts a cheeseburger as equivalent to 1.25 hamburgers and chicken sandwiches as 0.8 hamburger. Current employment is five full-time employees who work a 40-hour week. If the restaurant sold 700 hamburgers, 900 cheeseburgers, and 500 chicken sandwiches in one week, what is its productivity? What would its productivity have been if it had sold the same number of sandwiches (2,100) but the mix was 700 of each type?

10. 11.125, 10.675

INTERNET ENRICHMENT EXERCISE: HARLEY-DAVIDSON MOTORCYCLES

Harley-Davidson has developed a Web site that allows potential customers to customize their new motorcycles. Working from a "basic" model, the customer can choose from an assortment of bags, chrome covers, color schemes, exhausts, foot controls, mirrors, and other accessories. The Web-based application is set up so that the customer can not only select from the extensive list of accessories but also see exactly what the motorcycle will look like. These unique designs can be shared with friends and family by printing the final picture or transferring it via e-mail. What a slick way to sell motorcycles!

Internet

Adjustable Cells

CELL	NAME	FINAL VALUE	REDUCED COST	OBJECTIVE COEFFICIENT	ALLOWABLE INCREASE	ALLOWABLE DECREASE
B3	Changing Cells Cheese Burger	20	0	2.25	0.625	1.375
C3	Changing Cells Sloppy Joes	60	0.625	2	1E+30	0.625
D3	Changing Cells Taco	65	0	1.75	2.75	1.25
E3	Changing Cells Chili	55	2.5	2.5	1E+30	2.5

Constraints

CELL	NAME	FINAL VALUE	SHADOW PRICE	CONSTRAINT R.H. SIDE	ALLOWABLE INCREASE	ALLOWABLE DECREASE
F11	Ground Beef (lbs.) Total	59.25	0.00	100	1E+30	40.75
F12	Cheese (lbs.) Total	32.50	0.00	50	1E+30	17.5
F13	Beans (lbs.) Total	29.50	0.00	50	1E+30	20.5
F14	Lettuce (lbs.) Total	15.00	8.75	15	3	13
F15	Tomato (lbs.) Total	44.00	0.00	50	1E+30	6
F16	Buns Total	80.00	1.38	80	55	20
F17	Taco Shells Total	65.00	0.00	80	1E+30	15

We have highlighted the buns row to answer the question. We can see that buns have a shadow price of $1.38. This shadow price means that each additional bun will generate $1.38 of profit. We also can see that other foods such as ground beef have a shadow price of $0. The items with a shadow price of $0 add nothing to profit since we are currently not using all that we have now. The other important piece of information that we have on the buns is that they are only worth $1.38 up until the next 55 buns and that is why the allowable increase is 55. We also can see that a pound of lettuce is worth $8.75. It might be wise to also look for a rush supplier of lettuce so we can increase our profit on Friday nights.

Acceptable answers to the questions are as follows:

1 *What is the best mix of the Friday night specials to maximize Joe Bob's revenue?*
20 cheese burgers, 60 Sloppy Joes, 65 tacos, and 55 bowls of chili.

2 *If a supplier offered to provide a rush order of buns at $1.00 a bun, is it worth the money?*
Yes, each additional bun brings in $1.38, so if they cost us $1, then we will net $0.38 per bun. However, this is only true up to 55 additional buns.

PROBLEMS

1 Solve the following problem with Excel Solver:

$$\text{Maximize } Z = 3X + Y.$$
$$12X + 14Y \leq 85$$
$$3X + 2Y \leq 18$$
$$Y \leq 4$$

1. $X = 6$;
$Y = 0$;
$Z = 18$.

2 Solve the following problem with Excel Solver:

$$\text{Minimize } Z = 2A + 4B.$$
$$4A + 6B \geq 120$$
$$2A + 6B \geq 72$$
$$B \geq 10$$

2. See ISM;
Optimal combination is $B = 10$; $A = 15$;
$Z = 70$.

3 A manufacturing firm has discontinued production of a certain unprofitable product line. Considerable excess production capacity was created as a result. Management is considering devoting this excess capacity to one or more of three products: X_1, X_2, and X_3.

3. *a.* See ISM for *a* and *b*.

   c. $X_1 = 45$;

   $X_2 = 100$;

   $X_3 = 80$;

   $Z = 2{,}140$ (maximum profit).

   d. Milling machines at capacity; lathes at capacity; grinders have 150 hours' slack; X_3 is at maximum sales capacity.

   e. Recommend working 200 hrs. O.T. in milling.

4. *a.* $600A + 900B \leq 3{,}600$

   $600A + 900B \geq 1{,}800$

   $200A + 700B \leq 1{,}400$

   $400A + 100B \geq 400$

   $A \leq 2$

   Minimize $.75A + .15B$

   b. $A = 0.54$, $B = 1.85$,

   Obj = 0.68.

5. Cost per student:

   $A = 0.75$;

   $B = 1.5$;

   Obj = 5.06.

6. *a.* $A + B \geq 3{,}000$

   $A + B \leq 4{,}000$

   $A \leq 2{,}000$

   $B \leq 4{,}000$

   $90A + 75B \geq 80(A + B)$, or

   $10A - 5B \geq 0$

   b. Optimum:

   $A = 1{,}000$;

   $B = 2{,}000$.

Machine hours required per unit are

	Product		
Machine Type	X_1	X_2	X_3
Milling machine	8	2	3
Lathe	4	3	0
Grinder	2	0	1

The available time in machine hours per week is

	Machine Hours per Week
Milling machines	800
Lathes	480
Grinders	320

The salespeople estimate they can sell all the units of X_1 and X_2 that can be made. But th sales potential of X_3 is 80 units per week maximum.

Unit profits for the three products are

	Unit Profits
X_1	$20
X_2	6
X_3	8

a. Set up the equations that can be solved to maximize the profit per week.

b. Solve these equations using the Excel Solver.

c. What is the optimal solution? How many of each product should be made, and what shoul the resultant profit be?

d. What is this situation with respect to the machine groups? Would they work at capacity, o would there be unused available time? Will X_3 be at maximum sales capacity?

e. Suppose that an additional 200 hours per week can be obtained from the milling machine by working overtime. The incremental cost would be $1.50 per hour. Would you recommen doing this? Explain how you arrived at your answer.

4 A diet is being prepared for the University of Arizona dorms. The objective is to feed the stu dents at the least cost, but the diet must have between 1,800 and 3,600 calories. No more tha 1,400 calories can be starch, and no fewer than 400 can be protein. The varied diet is to be mac of two foods: *A* and *B*. Food *A* costs $0.75 per pound and contains 600 calories, 400 of whic are protein and 200 starch. No more than two pounds of food *A* can be used per resident. Foo *B* costs $0.15 per pound and contains 900 calories, of which 700 are starch, 100 are protei and 100 are fat.

a. Write the equations representing this information.

b. Solve the problem graphically for the amounts of each food that should be used.

5 Do Problem 4 with the added constraint that not more than 150 calories shall be fat a that the price of food has escalated to $1.75 per pound for food *A* and $2.50 per pound f food *B*.

6 Logan Manufacturing wants to mix two fuels, *A* and *B*, for its trucks to minimize cost. It nee no fewer than 3,000 gallons to run its trucks during the next month. It has a maximum fi storage capacity of 4,000 gallons. There are 2,000 gallons of fuel *A* and 4,000 gallons of fue available. The mixed fuel must have an octane rating of no less than 80.

When fuels are mixed, the amount of fuel obtained is just equal to the sum of the amou put in. The octane rating is the weighted average of the individual octanes, weighted in prop tion to the respective volumes.

The following is known: Fuel *A* has an octane of 90 and costs $1.20 per gallon. Fuel *B* an octane of 75 and costs $0.90 per gallon.

a. Write the equations expressing this information.

b. Solve the problem using the Excel Solver, giving the amount of each fuel to be used. S any assumptions necessary to solve the problem.

2. *a.* See ISM.
   b. A–C–D–E–G.
   c. 26 weeks.
   d. Six weeks (15 – 9).

2 The following activities are part of a project to be scheduled using CPM:

ACTIVITY	IMMEDIATE PREDECESSOR	TIME (WEEKS)
A	—	6
B	A	3
C	A	7
D	C	2
E	B, D	4
F	D	3
G	E, F	7

a. Draw the network.
b. What is the critical path?
c. How many weeks will it take to complete the project?
d. How much slack does activity B have?

3. *a.* See ISM.
   b. A–B–D–E–H.
   c. 15 weeks.
   d. C, 3 weeks; F, 1 week; G, 1 week.

3 Schedule the following activities using CPM:

ACTIVITY	IMMEDIATE PREDECESSOR	TIME (WEEKS)
A	—	1
B	A	4
C	A	3
D	B	2
E	C, D	5
F	D	2
G	F	2
H	E, G	3

a. Draw the network.
b. What is the critical path?
c. How many weeks will it take to complete the project?
d. Which activities have slack, and how much?

4. *a.* See ISM.
   b. A–C–F–G–I, and A–D–F–G–I.
   c. C: one week;
   D: one week;
   G: one week.
   d. Two paths:
   A–C–F–G–I and
   A–D–F–G–I, 16 weeks.

4 The R&D department is planning to bid on a large project for the development of a new communication system for commercial planes. The accompanying table shows the activities, times, and sequences required:

ACTIVITY	IMMEDIATE PREDECESSOR	TIME (WEEKS)
A	—	3
B	A	2
C	A	4
D	A	4
E	B	6
F	C, D	6
G	D, F	2
H	D	3
I	E, G, H	3

a. Draw the network diagram.
b. What is the critical path?
c. Suppose you want to shorten the completion time as much as possible, and you have the option of shortening any or all of B, C, D, and G each one week. Which would you shorten?
d. What is the new critical path and earliest completion time?

5 A construction project is broken down into the following 10 activities:

ACTIVITY	IMMEDIATE PREDECESSOR	TIME (WEEKS)
1	—	4
2	1	2
3	1	4
4	1	3
5	2, 3	5
6	3	6
7	4	2
8	5	3
9	6, 7	5
10	8, 9	7

a. Draw the network diagram.
b. Find the critical path.
c. If activities 1 and 10 cannot be shortened, but activities 2 through 9 can be shortened to a minimum of one week each at a cost of $10,000 per week, which activities would you shorten to cut the project by four weeks?

5. *a.* See ISM.
b. 1–3–6–9–10.
c. See ISM.

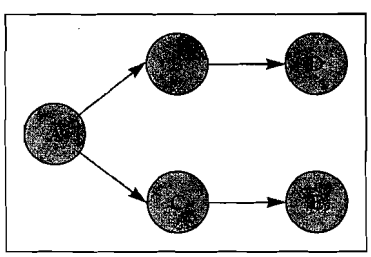
6 The following represents a project that should be scheduled using CPM:

ACTIVITY	IMMEDIATE PREDECESSORS	TIMES (DAYS) *a*	*m*	*b*
A	—	1	3	5
B	—	1	2	3
C	A	1	2	3
D	A	2	3	4
E	B	3	4	11
F	C, D	3	4	5
G	D, E	1	4	6
H	F, G	2	4	5

a. Draw the network.
b. What is the critical path?
c. What is the expected project completion time?
d. What is the probability of completing this project within 16 days?

6. *a.* See ISM.
b. B–E–G–H.
c. 14.67 days.
d. $P(<16) = .7852$.

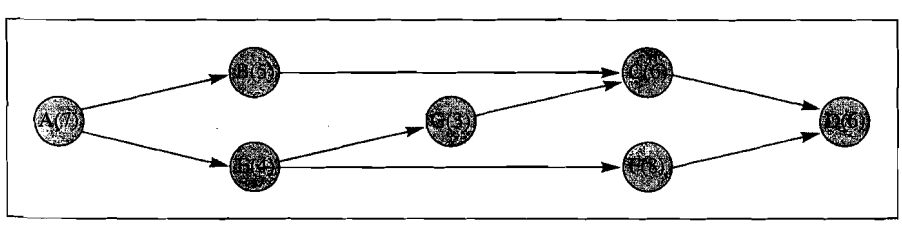
7 There is an 82% chance the project below can be completed in X weeks or less. What is X?



ACTIVITY	MOST OPTIMISTIC	MOST LIKELY	MOST PESSIMISTIC
A	2	5	11
B	3	3	3
C	1	3	5
D	6	8	10
E	4	7	10

7. ABD 16.5
ACE 15.5
$.92 = \frac{X - 16.5}{\sqrt{2.694}}$
$X = 18$

8 Here is a CPM network with activity times in weeks:



a. Determine the critical path.
b. How many weeks will the project take to complete?
c. Suppose F could be shortened by two weeks and B by one week. How would this affect the completion date?

8. *a.* Critical path is A–E–G–C–D.
b. 26 weeks.
c. See ISM.
No difference in completion date.

a. Identify the critical path.
b. What is the length of time to complete the project?
c. Which activities have slack, and how much?
d. Here is a table of normal and crash times and costs. Which activities would you shorten to cut two weeks from the schedule in a rational fashion? What would be the incremental cost? Is the critical path changed?

Activity	Normal Time	Crash Time	Normal Cost	Crash Cost	Possible Number of Weeks Decrease	Cost/Week to Expedite
A	7	6	$7,000	$ 8,000		
B	2	1	5,000	7,000		
C	4	3	9,000	10,200		
D	5	4	3,000	4,500		
E	2	1	2,000	3,000		
F	4	2	4,000	7,000		
G	5	4	5,000	8,000		

15. *a.*

Activity	Expected Time	Variance
A	5.00	1.00
B	5.00	1.78
C	6.17	0.69
D	2.00	0.00
E	3.00	1.78
F	3.83	0.25
G	7.50	1.36
H	2.00	0.11

b. See ISM for diagram.

c. A–C–G–H.

d. $Z = \dfrac{19 - 20.67}{\sqrt{1 + \frac{25}{36} + 1\frac{1}{3} + \frac{1}{9}}}$

$= -.9384$

$P(Z < -.9384) = 17$ percent.

16. *a.* See ISM.

b. See ISM.

c. A–B–E–G–I.

d. $Z = \dfrac{26 - 24.67}{\sqrt{\frac{25}{36} + 1\frac{7}{9} + 1\frac{7}{9} + 1\frac{13}{36} + \frac{4}{9}}}$

$= .5405$

$P(Z > .5405) = 29$ percent

$P(Z < .5405) = 71$ percent.

e. All the other paths will create problems since there is only 0.5 day of slack.

15 A project has been defined to contain the following activities, along with their time estimates for completion.

Activity	Time Estimates (wk) *a*	*m*	*b*	Immediate Predecessor
A	2	5	8	—
B	1	5	9	—
C	4	6	9	A
D	2	2	2	B
E	1	2	9	A
F	2	4	5	C, D
G	3	8	10	C, E
H	1	2	3	F, G

a. Calculate the expected time and the variance for each activity.
b. Draw the critical path diagram. Show the early start, early finish times and late start, late finish times.
c. Show the critical path.
d. What is the probability that the project can be completed in 19 weeks?

16 Hungry Henry's is building a new restaurant. In order to complete the project, the following activities, along with their time estimates, are given below.

Activity	Time Estimates (wk) *a*	*m*	*b*	Immediate Predecessor
A	2	4	7	—
B	1	4	9	A
C	3	6	9	A
D	2	3	5	B, C
E	1	3	9	B
F	2	4	5	C, D
G	3	8	10	E
H	1	2	3	F, E
I	3	5	7	G, H

a. Calculate the expected time and the variance for each activity.
b. Draw the critical path diagram. Show the early start, early finish times and late start, late finish times.
c. Show the critical path.
d. What is the probability that the project can be completed in 26 weeks? What is the probability it will take longer than 26 weeks?
e. Are there any other paths that can interfere with completing this project on time?

17 Bragg's Bakery is building a new automated bakery in downtown Sandusky. Here are the activities that need to be completed to get the new bakery built and the equipment installed.

ACTIVITY	PREDECESSOR	NORMAL TIME (WEEKS)	CRASH TIME (WEEKS)	EXPEDITING COST/WEEK
A	—	9	6	$3,000
B	A	8	5	$3,500
C	A	15	10	$4,000
D	B, C	5	3	$2,000
E	C	10	6	$2,500
F	D, E	2	1	$5,000

a. Draw the project diagram.
b. What is the normal project length?
c. What is the project length if all activities are crashed to their minimum?
d. Bragg's loses $3,500 in profit per week for every week the bakery is not completed. How many weeks will the project take if we are willing to pay crashing cost as long as it is less than $3,500?

17. *a.* See ISM for diagram.
b. and *c.*

PATH	NORMAL LENGTH	CRASHED LENGTH
ABDF	24	15
ACDF	31	20
ACEF	36	23

d. Only crash to 29 weeks.

ADVANCED PROBLEM

18 Assume the network and data that follow:

ACTIVITY	NORMAL TIME (WEEKS)	NORMAL COST	CRASH TIME (WEEKS)	CRASH COST	IMMEDIATE PREDECESSORS
A	2	$50	1	$70	—
B	4	80	2	160	A
C	8	70	4	110	A
D	6	60	5	80	A
E	7	100	6	130	B
F	4	40	3	100	D
G	5	100	4	150	C, E, F

a. Construct the network diagram.
b. Indicate the critical path when normal activity times are used.
c. Compute the minimum total direct cost for each project duration based on the cost associated with each activity. Consider durations of 13, 14, 15, 16, 17, and 18 weeks.
d. If the indirect costs for each project duration are $400 (18 weeks), $350 (17 weeks), $300 (16 weeks), $250 (15 weeks), $200 (14 weeks), and $150 (13 weeks), what is the total project cost for each duration? Indicate the minimum total project cost duration.

18. *a.* See ISM.
b. A–B–E–G.
c. 13 = $760
14 = $660
15 = $600
16 = $550
17 = $520
18 = $500
d. 13 = $910
14 = $860
15 = $850
16 = $850
17 = $870
18 = $900
Minimum cost either 15 or 16 days, probably prefer 15.

CASE: THE CAMPUS WEDDING (A)

On March 31 of last year, Mary Jackson burst into the family living room and announced that she and Larry Adams (her college boyfriend) were going to be married. After recovering from the shock, her mother hugged her and asked, "When?" The following conversation resulted:

Mary: April 22.

Mother: What!

Father: The Adams–Jackson wedding will be the social hit of the year. Why so soon?

Mary: Because on April 22 the cherry blossoms on campus are always in full bloom! The wedding pictures will be beautiful.

Mother: But honey, we can't possibly finish all the things that need to be done by then. Remember all the details that were involved in your sister's wedding? Even if we start tomorrow, it takes a day to reserve the church and reception hall, and they need at least 17 days' notice. That has to be done before we can start decorating the church, which takes three days. An extra $100 contribution on Sunday would probably cut that 17-day notice to 10 days, though.

Father: Ugh!

Mary: I want Jane Summers to be my maid of honor.

Father: But she's in the Peace Corps, in Guatemala, isn't she? It would take her 10 days to get ready and drive up here.

Mary: But we could fly her up in two days, and it would cost only $500. She would have to be here in time to have her dress fitted.

Father: Ugh!

4 What priority rule do you use in scheduling your study time for midterm examinations? If you have five exams to study for, how many alternative schedules exist?
5 The SOT rule provides an optimal solution in a number of evaluation criteria. Should the manager of a bank use the SOT rule as a priority rule? Why?
6 Data integrity is a big deal in industry. Why?
7 Why does batching cause so much trouble in work centers?
8 What job characteristics would lead you to schedule jobs according to "longest processing time first"?
9 Why is managing bottlenecks so important in work-center scheduling?
10 Under what conditions is the assignment method appropriate?
11 How might planning for a special customer affect the personnel schedule in a service?

PROBLEMS

1. Mean flow time = 16.2 days.

1 The following table gives the operation times and due dates for five jobs which are to be processed on a machine. Assign the jobs according to the shortest operation time and calculate the mean flow time.

JOB	PROCESSING TIME	DUE DATE (DAYS HENCE)
101	6 days	5
102	7 days	3
103	4 days	4
104	9 days	7
105	5 days	2

2. J-432 to C
J-487 to B
J-492 to A
Cost = $25.

2 The MediQuick lab has three lab technicians available to process blood samples and three jobs that need to be assigned. Each technician can do only one job. The table below represents the lab's estimate (in dollars) of what it will cost for each job to be completed. Assign the technicians to the jobs to minimize costs.

JOB	TECH A	TECH B	TECH C
J-432	11	14	6
J-487	8	10	11
J-492	9	12	7

3.

CAR	PRIORITY
C	First
A	Tie for second
B	Tie for second

3 Christine has three cars that must be overhauled by her ace mechanic, Megan. Given the following data about the cars, use least slack per remaining operation to determine Megan's scheduling priority for each:

CAR	CUSTOMER PICK-UP TIME (HOURS HENCE)	REMAINING OVERHAUL TIME (HOURS)	REMAINING OPERATION
A	10	4	Painting
B	17	5	Wheel alignment, painting
C	15	1	Chrome plating, painting, seat repair

4. See table.

4 A hotel has to schedule its receptionists according to hourly loads. Management has identified the number of receptionists needed to meet the hourly requirement, which changes from day to day. Assume each receptionist works a four-hour shift. Given the following staffing requirement in a certain day, use the first-hour principle to find the personnel schedule:

	PERIOD											
	8 A.M.	9 A.M.	10 A.M.	11 A.M.	NOON	1 P.M.	2 P.M.	3 P.M.	4 P.M.	5 P.M.	6 P.M.	7 P.M.
Requirement	2	3	5	8	8	6	5	8	8	6	4	3
Assigned	2	1	2	3	2			6	2			1
On duty	2	3	5	8	8	7	5	8	8	8	8	3

Johnson's Rule

5 Seven jobs must be processed in two operations: A and B. All seven jobs must go through A and B in that sequence—A first, then B. Determine the optimal order in which the jobs should be sequenced through the process using these times:

JOB	PROCESS A TIME	PROCESS B TIME
1	9	6
2	8	5
3	7	7
4	6	3
5	1	2
6	2	6
7	4	7

5. JOB ORDER
5
6
7
3
1
2
4

6 Jumbo's Restaurant is trying to create a consecutive-days-off schedule that uses the fewest workers. Use the following information to create a five-days-on, two-days-off schedule:

	DAY						
	M	TU	W	TH	F	S	SU
Requirements	2	2	1	3	3	4	2

6. 4 workers: 2–TuW, 1–SuM, 1–WTh, answers may vary.

7 The following list of jobs in a critical department includes estimates of their required times:

JOB	REQUIRED TIME (DAYS)	DAYS TO DELIVERY PROMISE	SLACK
A	8	12	4
B	3	9	6
C	7	8	1
D	1	11	10
E	10	−10 (late)	−20
F	6	10	4
G	5	−8 (late)	−13
H	4	6	2

a. Use the shortest operation time rule to schedule these jobs.
What is the schedule?
What is the mean flow time?

b. The boss does not like the schedule in *a*. Jobs E and G must be done first, for obvious reasons. (They are already late.) Reschedule and do the best you can while scheduling Jobs E and G first and second, respectively.
What is the new schedule?
What is the new mean flow time?

7. *a.* Schedule: DBHGFCAE.
Total flow time = 149
Mean flow time = 149/8 = 18.625 days.
b. E 10 days
G 5
D 1
B 3
H 4
F 6
C 7
A 8
Mean flow time = 192/8 = 24 days.

8 The following matrix shows the costs in thousands of dollars for assigning Individuals A, B, C, and D to Jobs 1, 2, 3, and 4. Solve the problem showing your final assignments in order to minimize cost.

	JOBS			
INDIVIDUALS	1	2	3	4
A	7	9	3	5
B	3	11	7	6
C	4	5	6	2
D	5	9	10	12

8. Worker A—Job 3;
Worker B—Job 1;
Worker C—Job 4;
Worker D—Job 2;
Cost = $17,000.

the company estimates that the discounted revenues would be $14 million. In either case, the probability of demand being high is .40, and the probability of it being low is .60. Not constructing a new factory would result in no additional revenue being generated because the current factories cannot produce these new products. Construct a decision tree to help Expando make the best decision.

6. See ISM.

Rezoned shopping center = $4.3 million.

Rezoned apartments = $3.9 million.

No rezoning = $0.4 million.

Expected results:

.60(1.3) + 0.40(0.4) = $0.94 million.

6 A builder has located a piece of property that she would like to buy and eventually build on. The land is currently zoned for four homes per acre, but she is planning to request new zoning. What she builds depends on approval of zoning requests and your analysis of this problem to advise her. With her input and your help, the decision process has been reduced to the following costs, alternatives, and probabilities:

Cost of land: $2 million.

Probability of rezoning: .60.

If the land is rezoned, there will be additional costs for new roads, lighting, and so on, of $1 million.

If the land is rezoned, the contractor must decide whether to build a shopping center or 1,500 apartments that the tentative plan shows would be possible. If she builds a shopping center, there is a 70 percent chance that she can sell the shopping center to a large department chain for $4 million over her construction cost, which excludes the land; and there is a 30 percent chance that she can sell it to an insurance company for $5 million over her construction cost (also excluding the land). If, instead of the shopping center, she decides to build the 1,500 apartments, she places probabilities on the profits as follows: There is a 60 percent chance that she can sell the apartments to a real estate investment corporation for $3,000 each over her construction cost; there is a 40 percent chance that she can get only $2,000 each over her construction cost. (Both exclude the land cost.)

If the land is not rezoned, she will comply with the existing zoning restrictions and simply build 600 homes, on which she expects to make $4,000 over the construction cost on each one (excluding the cost of land).

Draw a decision tree of the problem and determine the best solution and the expected net profit.

7. Machine A

EV = .9 × $45K

= $41,500

Machine B

EV = .5 × $80K

= $40,000

7 If the payoff of selecting Machine A is $40,500 with a probability of 90% and the payoff of selecting Machine B is $80,000 with a probability of 50%, which machine would you select if maximizing payoff is your objective?

8. 300/400 = .75

8 If the best operating rate for a machine is 400 units per hour and the actual capacity used during an hour is 300 units, what is the capacity utilization rate?

9. Lease = $15,000

Drill = .16 × −100K

+ .4 × 50K

+ .24 × 100K

+ .2 × 200K

= $68K

9 A company owns a lease granting it the right to explore for oil on a certain piece of property. They may sell the lease for $15,000 and let another company take the risk or they may drill hoping to find oil and/or gas. The four possible drilling outcomes are listed below, together with probabilities of occurrence and payoffs.

POSSIBLE OUTCOME	PROBABILITY	PAYOFF
Dry well	0.16	−$100,000
Gas well only	0.40	50,000
Oil and gas combination	0.24	100,000
Oil well	0.20	200,000

Draw a decision tree for this problem. Should the company drill or should they sell the lease?

10. Lease = $25K

Overtime = .3 × 5K × 3

+ .5 × 10K × 3

+ .2 × 15K × 3

= $28.5K

10 The Plastic Production Company needs to expand its production capacity. This can be done in one of two ways: using overtime in its current plant or leasing another plant. Overtime has a cost penalty (above regular time) of $3 per case of product produced, and can only be used for up to 15,000 cases per year. Leasing another plant would entail an annual fixed leasing cost of $25,000; however, the workforce of this pant would be paid on a regular time basis and could produce any number of cases up to a maximum of 20,000 cases annually.

The company estimates that additional demand (beyond what can be produced in its current plant in regular time) may take on the following values, with corresponding probabilities:

Solution

a. Learning rate = 9 minutes/10 minutes = 90%
From Exhibit 5A.4, the time for the 1,000th unit is .3499 × 10 minutes = 3.499 minutes. Yes, hire the person.

b. From Exhibit 5A.4, unit 10 at 90% is .7047. Therefore, the time for the 10th unit = .7047 × 10 = 7.047 minutes.

c. More data should be collected on the job applicant's performance.

SOLVED PROBLEM 2

Excel: Learning Curves

Boeing Aircraft collected the following cost data on the first 8 units of its new business jet.

UNIT NUMBER	COST ($ MILLIONS)	UNIT NUMBER	COST ($ MILLIONS)
1	$100	5	60
2	83	6	57
3	73	7	53
4	62	8	51

a. Estimate the learning curve for the new business jet.

b. Estimate the average cost for the first 1,000 units of the jet.

c. Estimate the cost to produce the 1,000th jet.

Solution

a. First, estimate the learning curve rate by calculating the average learning rate with each doubling of production.

$$\text{Units 1 to 2} = 83/100 = 83\%$$
$$\text{Units 2 to 4} = 62/83 = 74.7\%$$
$$\text{Units 4 to 8} = 51/62 = 82.26\%$$
$$\text{Average} = (83 + 74.4 + 82.6)/3 = 80\%$$

b. The average cost of the first 1,000 units can be estimated using Exhibit 5A.5. The cumulative improvement factor for the 1,000th unit at 80 percent learning is 158.7. The cost to produce the first 1,000 units is

$$\$100\text{M} \times 158.7 = \$15{,}870\text{M}$$

The average cost for each of the first 1,000 units is

$$\$15{,}870\text{M}/1{,}000 = \$15.9\text{M}$$

c. To estimate the cost to produce the 1,000th unit, use Exhibit 5A.4.
The unit improvement factor for the 1,000th unit at 80 percent is .1082.
The cost to produce the 1,000th unit is

$$\$100\text{M} \times .1082 = \$10.82\text{M}$$

REVIEW AND DISCUSSION QUESTIONS

1 If you kept any of your old exam grades from last semester, get them out and write down the grades. Use Exhibits 5A.4 and 5A.5, use log-log graph paper, or use a spreadsheet to find whether the exponential curve fits, showing that you experienced learning over the semester (insofar as your exam performance is concerned). If not, can you give some reasons why not?

2 How might the following business specialists use learning curves: accountants, marketers, financial analysts, personnel managers, and computer programmers?

3 As a manager, which learning percentage would you prefer (other things being equal), 110 percent or 60 percent? Explain.

4 What difference does it make if a customer wants a 10,000-unit order produced and delivered all at one time or in 2,500-unit batches?

PROBLEMS

1 A time standard was set as 0.20 hour per unit based on the 50th unit produced. If the task has a 90 percent learning curve, what would be the expected time of the 100th, 200th, and 400th units?

1. 100th = 0.18 hr.
200th = 0.16 hr.
400th = 0.15 hr.

2 You have just received 10 units of a special subassembly from an electronics manufacturer at a price of $250 per unit. A new order also has just come in for your company's product that uses these subassemblies, and you wish to purchase 40 more to be shipped in lots of 10 units each. (The subassemblies are bulky, and you need only 10 a month to fill your new order.)

a. Assuming a 70 percent learning curve by your supplier on a similar product last year, how much should you pay for each lot? Assume that the learning rate of 70 percent applies to each lot of 10 units, not each unit.

b. Suppose you are the supplier and can produce 20 units now but cannot start production on the second 20 units for two months. What price would you try to negotiate for the last 20 units?

3 Johnson Industries received a contract to develop and produce four high-intensity long-distance receiver/transmitters for cellular telephones. The first took 2,000 labor hours and $39,000 worth of purchased and manufactured parts; the second took 1,500 labor hours and $37,050 in parts; the third took 1,450 labor hours and $31,000 in parts; and the fourth took 1,275 labor hours and $31,492 in parts.

Johnson was asked to bid on a follow-on contract for another dozen receiver/transmitter units. Ignoring any forgetting factor effects, what should Johnson estimate time and parts costs to be for the dozen units? (Hint: There are two learning curves—one for labor and one for parts.)

4 Lambda Computer Products competed for and won a contract to produce two prototype units of a new type of computer that is based on laser optics rather than on electronic binary bits.

The first unit produced by Lambda took 5,000 hours to produce and required $250,000 worth of material, equipment usage, and supplies. The second unit took 3,500 hours and used $200,000 worth of materials, equipment usage, and supplies. Labor is $30 per hour.

a. Lambda was asked to present a bid for 10 additional units as soon as the second unit was completed. Production would start immediately. What would this bid be?

b. Suppose there was a significant delay between the contracts. During this time, personnel and equipment were reassigned to other projects. Explain how this would affect the subsequent bid.

5 You've just completed a pilot run of 10 units of a major product and found the processing time for each unit was as follows:

UNIT NUMBER	TIME (HOURS)
1	970
2	640
3	420
4	380
5	320
6	250
7	220
8	207
9	190
10	190

a. According to the pilot run, what would you estimate the learning rate to be?

b. Based on *a*, how much time would it take for the next 190 units, assuming no loss of learning?

c. How much time would it take to make the 1,000th unit?

6 Lazer Technologies Inc. (LTI) has produced a total of 20 high-power laser systems that could be used to destroy any approaching enemy missiles or aircraft. The 20 units have been produced, funded in part as private research within the research and development arm of LTI, but the bulk of the funding came from a contract with the U.S. Department of Defense (DoD).

Testing of the laser units has shown that they are effective defense weapons, and through redesign to add portability and easier field maintenance, the units could be truck-mounted.

DoD has asked LTI to submit a bid for 100 units.

The 20 units that LTI has built so far cost the following amounts and are listed in the order in which they were produced:

UNIT NUMBER	COST ($ MILLIONS)	UNIT NUMBER	COST ($ MILLIONS)
1	$12	11	$3.9
2	10	12	3.5
3	6	13	3.0

(continued)

2. *a.*
   1st 10 units = $2,500.00
   2nd 10 units = 1,750.00
   3rd 10 units = 1,420.50
   4th 10 units = 1,225.00
   5th 10 units = 1,092.00
   b. Between max. of $4,250 and min. of $2,645.50.

3. LR parts, 90%, LR labor, 80%
   Labor: 11,556 hours.
   Parts: $330,876.

4. *a.* Labor, $570,150. Materials, 1,356,750 plus something for profit.
   b. Need to consider forgetting and relearning. Time and cost could be much higher.

5. *a.* From log-log plot, LR = 60%
   b. About 8,029 hours.
   c. 6.0 hours.

UNIT NUMBER	COST ($ MILLIONS)	UNIT NUMBER	COST ($ MILLIONS)
4	6.5	14	2.8
5	5.8	15	2.7
6	6	16	2.7
7	5	17	2.3
8	3.6	18	3.0
9	3.6	19	2.9
10	4.1	20	2.6

a. Based on past experience, what is the learning rate?
b. What bid should LTI submit for the total order of 100 units, assuming that learning continues?
c. What is the cost expected to be for the last unit under the learning rate you estimated?

7 Jack Simpson, contract negotiator for Nebula Airframe Company, is currently involved in bidding on a follow-up government contract. In gathering cost data from the first three units, which Nebula produced under a research and development contract, he found that the first unit took 2,000 labor hours, the second took 1,800 labor hours, and the third took 1,692 hours.

In a contract for three more units, how many labor hours should Simpson plan for?

8 Honda Motor Company has discovered a problem in the exhaust system of one of its automobile lines and has voluntarily agreed to make the necessary modifications to conform with government safety requirements. Standard procedure is for the firm to pay a flat fee to dealers for each modification completed.

Honda is trying to establish a fair amount of compensation to pay dealers and has decided to choose a number of randomly selected mechanics and observe their performance and learning rate. Analysis demonstrated that the average learning rate was 90 percent, and Honda then decided to pay a $60 fee for each repair (3 hours × $20 per flat-rate hour).

Southwest Honda, Inc., has complained to Honda Motor Company about the fee. Six mechanics, working independently, have completed two modifications each. All took 9 hours on the average to do the first unit and 6.3 hours to do the second. Southwest refuses to do any more unless Honda allows at least 4.5 hours. The dealership expects to perform the modification to approximately 300 vehicles.

What is your opinion of Honda's allowed rate and the mechanics' performance?

9 United Research Associates (URA) had received a contract to produce two units of a new cruise missile guidance control. The first unit took 4,000 hours to complete and cost $30,000 in materials and equipment usage. The second took 3,200 hours and cost $21,000 in materials and equipment usage. Labor cost is charged at $18 per hour.

The prime contractor has now approached URA and asked to submit a bid for the cost of producing another 20 guidance controls.

a. What will the last unit cost to build?
b. What will be the average time for the 20 missile guidance controls?
c. What will the average cost be for guidance control for the 20 in the contract?

10 United Assembly Products (UAP) has a personnel screening process for job applicants to test their ability to perform at the department's long-term average rate. UAP has asked you to modify the test by incorporating learning theory. From the company's data, you discovered that if people can perform a given task in 30 minutes or less on the 20th unit, they achieve the group long-run average. Obviously, all job applicants cannot be subjected to 20 performances of such a task, so you are to determine whether they will likely achieve the desired rate based on only 2 performances.

a. Suppose a person took 100 minutes on the first unit and 80 minutes on the second. Should this person be hired?
b. What procedure might you establish for hiring (i.e., how to evaluate the job applicant's two performances)?
c. What is a significant limitation of this analysis?

11 A potentially large customer offered to subcontract assembly work that is profitable only if you can perform the operations at an average time of less than 20 hours each. The contract is for 1,000 units.

You run a test and do the first one in 50 hours and the second one in 40 hours.

a. How long would you expect the third one to take?
b. Would you take the contract? Explain.

12 Western Turbine, Inc., has just completed the production of the 10th unit of a new high-efficiency turbine/generator. Its analysis showed that a learning rate of 85 percent existed over the production of the 10 units. If the 10th unit contained labor costs of $2.5 million, what price should Western Turbine charge for labor on units 11 and 12 to make a profit of 10 percent of the selling price?

6. *a.* 70%
b. $145,956,000.
c. Cost = .0851 × $12 M = $1,021,200.

7. 4,710 hours.

8. Learning rate = 70%; unreasonable to ask for 4.5 hours. After 25, average repetitions time is about 3 hours.

9. *a.* Cost of 22nd unit = $32,732.40.
b. 1,886 hours.
c. Average cost = $43,126.50.

10. *a.* If first unit is 100 minutes, the learning rate needs to be 75%, not 80% (80/100). Do not hire.
b. See ISM.
c. See ISM.

11. *a.* 3rd = 35.1 hrs.
b. Average = 7.9 hrs. each; well worth it.

12. 11th 2.4476/.9 = $2.7196 million
12th 2.3953/.9 = $2.6615 million
$5.3811 million total

5 Your company's new process improvement guru is aggressive at providing and requiring online self-service at all levels of management, from making travel arrangements to doing check requests, travel expense reports, and even performance evaluations online. What advice would you give to the guru about this?

PROBLEMS

1. Correspondence to the guidelines for job design is an accurate predictor of the general level of subjective satisfaction.

1 Use the following form to evaluate a job you have held relative to the five principles of job design given in the chapter. Develop a numerical score by summing the numbers in parentheses.

	Poor (0)	Adequate (1)	Good (2)	Outstanding (3)
Task variety				
Skill variety				
Feedback				
Task identity				
Task autonomy				

a. Compute the score for your job. Does the score match your subjective feelings about the job as a whole? Explain.

b. Compare your score with the scores generated by your classmates. Is there one kind of job that everybody likes and one kind that everybody dislikes?

2. *a.* 1.35 minutes.
b. 1.51 minutes.

2 A time study was made of an existing job to develop new time standards. A worker was observed for 45 minutes. During that period, 30 units were produced. The analyst rated the worker as performing at a 90 percent performance rate. Allowances in the firm for rest and personal time are 12 percent.

a. What is the normal time for the task?

b. What is the standard time for the task?

3.

	Observation Times
(045)	8:45
(151)	9:51
(152)	9:52
(322)	11:22
(331)	11:31

3 The Bullington Company wants a time standard established on the painting operation of souvenir horseshoes for the local Pioneer Village. Work sampling is to be used. It is estimated that working time averages 95 percent of total time (working time plus idle time). A co-op student is available to do the work sampling between 8:00 a.m. and 12:00 noon. Sixty working days are to be used for the study. Use Exhibit 6A.5 and an absolute error of 2.5 percent. Use the table of random numbers (Appendix F) to calculate the sampling schedule for the first day (that is, show the times of day that an observation of working/idle should be made). Hint: Start random number selection with the first tour.

4. $ST = 0.558$ minute.

4 The final result of the study in Problem 3 estimated working time at 91.0 percent. In a 480-minute shift, the best operator painted 1,000 horseshoes. The student's performance index was estimated to be 115 percent. Total allowances for fatigue, personal time, and so on, are 10 percent. Calculate the standard time per piece.

5. $ST = 0.078$ min./doughnut.

5 Suppose you want to set a time standard for the baker making her specialty, square doughnuts. A work-sampling study of her on "doughnut day" yielded the following results:

Time spent (working and idle)	320 minutes
Number of doughnuts produced	5,000
Working time	280 minutes
Performance rating	125%
Allowances	10%

What is the standard time per doughnut?

6. *a.* $NT = 0.9286$ min./part.
b. $ST = 1.0679$ min./part.
c. Daily output = 449.50
Day's wages = $44.49.

6 In an attempt to increase productivity and reduce costs, Rho Sigma Corporation is planning to install an incentive pay plan in its manufacturing plant. In developing standards for one operation, time-study analysts observed a worker for 30 minutes. During that time, the worker completed 42 parts. The analysts rated the worker as producing at 130 percent. The base wage rate of the worker is $5 per hour. The firm has established 15 percent as a fatigue and personal time allowance.

a. What is the normal time for the task?

b. What is the standard time for the task?

c. If the worker produced 500 units during an eight-hour day, what wages would the worker have earned?

7 Because new regulations will greatly change the products and services offered by savings and loan associations, time studies must be performed on tellers and other personnel to determine the number and types of personnel needed and incentive wage payment plans that might be installed. As an example of the studies that the various tasks will undergo, consider the following problem and come up with appropriate answers.

A hypothetical case was set up in which the teller (to be retitled later as an *account adviser*) was required to examine a customer's portfolio and determine whether it was more beneficial for the customer to consolidate various CDs into a single issue currently offered, or to leave the portfolio unaltered. A time study made of the teller yielded the following findings:

Time of study	90 minutes
Number of portfolios examined	10 portfolios
Performance rating	130 percent
Rest for personal time	15 percent
Teller's proposed new pay rate	$12 per hour

a. What is the normal time for the teller to do a portfolio analysis for the CDs?
b. What is the standard time for the analysis?

8 Based on a manager's observations, a milling machine appears to be idle approximately 30 percent of the time. Develop a work-sampling plan to determine the percentage of idle time, accurate within a 3 percent error (±3%) with a 95 percent confidence level. Use the random numbers from Appendix B to derive the first day's sampling schedule (assume that the sample will take place over 60 days and that an eight-hour shift is used from 8:00 to 12:00 and 1:00 to 5:00).

9 In a time study at a producer of LCD televisions, a worker assembled 20 units in 100 minutes. The time study analyst rated the worker a performance rate of 110 percent. An allowance for personal time and fatigue is 15 percent. What are the normal time and standard time?

10 A bank manager wants to determine the percent of time that tellers are working and idle. She decides to use work sampling, and her initial estimate is that the tellers are idle 30 percent of the time. How many observations should the manager take in order to be 95 percent confident that the results will not be more than 2.5 percent away from the true result?

11 Decision Science Institute (DSI) promotes its annual national conference by mailing thousands of letters to various recipients. A time study has been conducted on the task of preparing the letters for mailing. On the basis of the observations below, DSI wants to develop a time standard for the task. The organization's personal, delay, and fatigue allowance factor is 15 percent. Compute the average cycle time and normal time for each element. Then, calculate the standard time for the entire task.

CYCLE OBSERVED IN MINUTES

JOB ELEMENT	1	2	3	4	5	PERFORMANCE RATING
(A) Compose letter	8	10	9	11	11	120%
(B) Print address labels	2	3	2	1	3	105%
(C) Stuff, seal, and sort envelopes	2	1	3	2	1	110%

7. *a.* $NT = 11.7$ min.
b. $ST = 13.455$ min./portfolio.

8. Sample size = 933. Approximately 16 observations per day. See IM for example of sampling schedule.

9. $100/20 = 5$
$5 \times 1.1 = 5.5 = NT$
$ST = 5.5(1 + .15)$
$= 6.325.$

10. 1344 observations.

11. Cycle time
A = 9.8 min
B = 2.2 min
C = 1.8 min
Normal Time
A = 11.76 min
B = 2.31 min
C = 1.98 min
Standard time for the task
$(11.76 + 2.31 + 1.98)/(1 - .15)$
$= 18.88$ min.

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FOOTNOTES

1 M. Apgar IV, "The Alternative Workplace: Changing Where and How People Work." *Harvard Business Review* 76, no. 3 (May–June 1998), pp. 121–36.

2 S. Lohr, "Slow Down, Brave Multitasker, and Don't Read This in Traffic," *New York Times*, March, 25, 2007.

3 C. Giffi, A. Roth, and G. M. Seal, *Competing in World-Class Manufacturing: America's 21st Century Challenge* (Homewood, IL: Richard D. Irwin, 1990), p. 299.

4. See ISM.

4 The purpose of this system design exercise is to gain experience in setting up a manufacturing process. (We suggest that this be done as a team project.) Assignment:
   a. Get one Ping-Pong paddle.
   b. Specify the type of equipment and raw materials you would need to manufacture that paddle, from the receipt of seasoned wood to packaging for shipment.
   c. Assume that one unit of each type of equipment is available to you. Further assume that you have a stock of seasoned wood and other materials needed to produce and box 100 paddles. Making reasonable assumptions about times and distances where necessary,
      (1) Develop an assembly drawing for the paddle.
      (2) Prepare an assembly chart for the paddle.
      (3) Develop a process flowchart for the paddle.
      (4) Develop a route sheet for the paddle.

5. *a.* See ISM for diagram; 5,600 components.
   b. 8,000; drilling operation.
   c. 9,600; final assembly operation.
   d. $1.81, $1.79.
   e. 100,840.

5 The Goodparts Company produces a component that is subsequently used in the aerospace industry. The component consists of three parts (A, B, and C) that are purchased from outside and cost 40, 35, and 15 cents per piece, respectively. Parts A and B are assembled first on assembly line 1, which produces 140 components per hour. Part C undergoes a drilling operation before being finally assembled with the output from assembly line 1. There are in total six drilling machines, but at present only three of them are operational. Each drilling machine drills part C at a rate of 50 parts per hour. In the final assembly, the output from assembly line 1 is assembled with the drilled part C. The final assembly line produces at a rate of 160 components per hour. At present, components are produced eight hours a day and five days a week. Management believes that if need arises, it can add a second shift of eight hours for the assembly lines.

The cost of assembly labor is 30 cents per part for each assembly line; the cost of drilling labor is 15 cents per part. For drilling, the cost of electricity is 1 cent per part. The total overhead cost has been calculated as $1,200 per week. The depreciation cost for equipment has been calculated as $30 per week.
   a. Draw a process flow diagram and determine the process capacity (number of components produced per week) of the entire process.
   b. Suppose a second shift of eight hours is run for assembly line 1 and the same is done for the final assembly line. In addition, four of the six drilling machines are made operational. The drilling machines, however, operate for just eight hours a day. What is the new process capacity (number of components produced per week)? Which of the three operations limits the capacity?
   c. Management decides to run a second shift of eight hours for assembly line 1 plus a second shift of only four hours for the final assembly line. Five of the six drilling machines operate for eight hours a day. What is the new capacity? Which of the three operations limits the capacity?
   d. Determine the cost per unit output for questions *b* and *c*.
   e. The product is sold at $4.00 per unit. Assume that the cost of a drilling machine (fixed cost) is $30,000 and the company produces 8,000 units per week. Assume that four drilling machines are used for production. If the company had an option to buy the same part at $3.00 per unit, what would be the break-even number of units?

6. *a.* 20,000 books
   b. Higher
   c. Lower

6 A book publisher has fixed costs of $300,000 and variable costs per book of $8.00. The book sells for $23.00 per copy.[3]
   a. How many books must be sold to break even?
   b. If the fixed cost increased, would the new break-even point be higher or lower?
   c. If the variable cost per unit decreased, would the new break-even point be higher or lower?

7. 7,500 units

7 A manufacturing process has a fixed cost of $150,000 per month. Each unit of product being produced contains $25 worth of material and takes $45 of labor. How many units are needed to break even if each completed unit has a value of $90?

8. *a.* 900 units
   b. 1,400 units
   c. 1,200 units
   1,800 units
   Impossible

8 Assume a fixed cost of $900, a variable cost of $4.50, and a selling price of $5.50.
   a. What is the break-even point?
   b. How many units must be sold to make a profit of $500.00?
   c. How many units must be sold to average $0.25 profit per unit? $0.50 profit per unit? $1.50 profit per unit?

9. 9,500 miles

9 Aldo Redondo drives his own car on company business. His employer reimburses him for such travel at the rate of 36 cents per mile. Aldo estimates that his fixed costs per year such as taxes, insurance, and depreciation are $2,052. The direct or variable costs such as gas, oil, and maintenance average about 14.4 cents per mile. How many miles must he drive to break even?

10 A firm is selling two products, chairs and bar stools, each at $50 per unit. Chairs have a variable cost of $25, and bar stools $20. Fixed cost for the firm is $20,000.

a. If the sales mix is 1:1 (one chair sold for every bar stool sold), what is the break-even point in dollars of sales? In units of chairs and bar stools?

b. If the sales mix changes to 1:4 (one chair sold for every four bar stools sold), what is the break-even point in dollars of sales? In units of chairs and bar stools?

10. *a.* $36,400 (364 of each)

b. $34,500 (138 chairs, 552 stools)

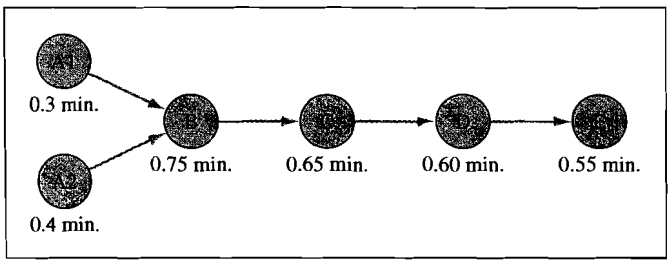
11 How would you characterize the most important difference for the following issues when comparing a job shop and a flow shop?

ISSUE	JOB SHOP	FLOW SHOP
Number of changeovers		
Labor content of product		
Flexibility		

11. Many, few
High, low
High, low

12 The diagram below represents a process where two components are made at stations A1 and A2 (one component is made at A1 and the other at A2). These components are then assembled at station B and moved through the rest of the process, where some additional work is completed at stations C, D, and E.

Assume that one and only one person is allowed at each station. Assume that the times given below for each station represent the amount of work that needs to be done at that station by that person, with no processing time variation. Assume that inventory is not allowed to build in the system.



What is the average hourly output of the process when it is in normal operation?

12. 80 units/hour

13 A certain custom engraving shop has traditionally had orders for between 1 and 50 units of whatever a customer orders. A large company has contacted this shop about engraving "reward" plaques (which are essentially identical to each other). It wants the shop to place a bid for this order. The volume is expected to be 12,000 units per year and will most likely last four years. To successfully bid (low enough price) for such an order, what will the shop likely have to do?

13. See ISM.

14 The product–process matrix is a convenient way of characterizing the relationship between product volumes (one-of-a-kind to continuous) and the processing system employed by a firm at a particular location. In the boxes presented below, describe the nature of the intersection between the type of shop (column) and process dimension (row).

	WORKSTATION	ASSEMBLY LINE
Engineering emphasis		
General workforce skill		
Statistical process control		
Facility layout		
WIP inventory level		

14. See ISM.

15 For each of the following variables, explain the differences (in general) as one moves from a workstation to an assembly line environment.

a. Throughput time (time to convert raw material into product).

b. Capital/labor intensity.

c. Bottlenecks.

15. *a.* See ISM.

b. See ISM.

c. Would probably decrease in an assembly line.

3. *a.* See ISM.
   b. 120 seconds.
   c. See ISM.
   d. 87.5%.

3 An assembly line is to operate eight hours per day with a desired output of 240 units per day. The following table contains information on this product's task times and precedence relationships:

TASK	TASK TIME (SECONDS)	IMMEDIATE PREDECESSOR
A	60	—
B	80	A
C	20	A
D	50	A
E	90	B, C
F	30	C, D
G	30	E, F
H	60	G

a. Draw the precedence diagram.
b. What is the workstation cycle time?
c. Balance this line using the longest task time.
d. What is the efficiency of your line balance?

4. *a.* See ISM.
   b. 75 seconds.
   c. See ISM.
   d. 91.7%

4 The desired daily output for an assembly line is 360 units. This assembly line will operate 450 minutes per day. The following table contains information on this product's task times and precedence relationships:

TASK	TASK TIME (SECONDS)	IMMEDIATE PREDECESSOR
A	30	—
B	35	A
C	30	A
D	35	B
E	15	C
F	65	C
G	40	E, F
H	25	D, G

a. Draw the precedence diagram.
b. What is the workstation cycle time?
c. Balance this line using the largest number of following tasks. Use the longest task time as a secondary criterion.
d. What is the efficiency of your line balance?

5. *a.* 27 seconds.
   b. 6 stations.
   c. 91.4%
   d. Work 45 minutes per day overtime.

5 Some tasks and the order in which they must be performed according to their assembly requirements are shown in the following table. These are to be combined into workstations to create an assembly line. The assembly line operates $7\frac{1}{2}$ hours per day. The output requirement is 1,000 units per day.

TASK	PRECEDING TASKS	TIME (SECONDS)	TASK	PRECEDING TASKS	TIME (SECONDS)
A	—	15	G	C	11
B	A	24	H	D	9
C	A	6	I	E	14
D	B	12	J	F, G	7
E	B	18	K	H, I	15
F	C	7	L	J, K	10

a. What is the workstation cycle time?
b. Balance the line using the longest task time based on the 1,000-unit forecast, stating which tasks would be done in each workstation.
c. For *b*, what is the efficiency of your line balance?
d. After production was started, Marketing realized that they understated demand and must increase output to 1,100 units. What action would you take? Be specific in quantitative terms, if appropriate.

4 Sharp Discounts Wholesale Club is considering consolidating its two service desks (see Problem 3) into one location, staffed by two clerks. The clerks will continue to work at the same individual speed of four minutes per customer.
   a. What is the probability of waiting in line?
   b. How many customers, on average, are waiting in line?
   c. How much time does a customer spend at the service desk (waiting plus service time)?
   d. Do you think the Sharp Discounts Wholesale Club should consolidate the service desks?

5 Burrito King (a new fast-food franchise opening up nationwide) has successfully automated burrito production for its drive-up fast-food establishments. The Burro-Master 9000 requires a constant 45 seconds to produce a batch of burritos. It has been estimated that customers will arrive at the drive-up window according to a Poisson distribution at an average of one every 50 seconds. To help determine the amount of space needed for the line at the drive-up window, Burrito King would like to know the expected average time in the system, the average line length (in cars), and the average number of cars in the system (both in line and at the window).

6 The Bijou Theater in Hermosa Beach, California, shows vintage movies. Customers arrive at the theater line at the rate of 100 per hour. The ticket seller averages 30 seconds per customer, which includes placing validation stamps on customers' parking lot receipts and punching their frequent watcher cards. (Because of these added services, many customers don't get in until after the feature has started.)
   a. What is the average customer time in the system?
   b. What would be the effect on customer time in the system of having a second ticket taker doing nothing but validations and card punching, thereby cutting the average service time to 20 seconds?
   c. Would system waiting time be less than you found in *b* if a second window was opened with each server doing all three tasks?

7 To support National Heart Week, the Heart Association plans to install a free blood pressure testing booth in El Con Mall for the week. Previous experience indicates that, on the average, 10 persons per hour request a test. Assume arrivals are Poisson from an infinite population. Blood pressure measurements can be made at a constant time of five minutes each. Assume the queue length can be infinite with FCFS discipline.
   a. What average number in line can be expected?
   b. What average number of persons can be expected to be in the system?
   c. What is the average amount of time that a person can expect to spend in line?
   d. On the average, how much time will it take to measure a person's blood pressure, including waiting time?
   e. On weekends, the arrival rate can be expected to increase to over 12 per hour. What effect will this have on the number in the waiting line?

8 A cafeteria serving line has a coffee urn from which customers serve themselves. Arrivals at the urn follow a Poisson distribution at the rate of three per minute. In serving themselves, customers take about 15 seconds, exponentially distributed.
   a. How many customers would you expect to see on the average at the coffee urn?
   b. How long would you expect it to take to get a cup of coffee?
   c. What percentage of time is the urn being used?
   d. What is the probability that three or more people are in the cafeteria?
   e. If the cafeteria installs an automatic vendor that dispenses a cup of coffee at a constant time of 15 seconds, how does this change your answers to *a* and *b*?

9 An engineering firm retains a technical specialist to assist four design engineers working on a project. The help that the specialist gives engineers ranges widely in time consumption. The specialist has some answers available in memory; others require computation, and still others require significant search time. On the average, each request for assistance takes the specialist one hour.

   The engineers require help from the specialist on the average of once each day. Because each assistance takes about an hour, each engineer can work for seven hours, on the average, without assistance. One further point: Engineers needing help do not interrupt if the specialist is already involved with another problem.

   Treat this as a finite queuing problem and answer the following questions:
   a. How many engineers, on average, are waiting for the technical specialist for help?
   b. What is the average time that an engineer has to wait for the specialist?
   c. What is the probability that an engineer will have to wait in line for the specialist?

10 L. Winston Martin (an allergist in Tucson) has an excellent system for handling his regular patients who come in just for allergy injections. Patients arrive for an injection and fill out a

4. *a.* 56%.
   b. 1.1 customers.
   c. 0.12 hour or 7.2 minutes.
   d. Yes.

5. $W_s = 4.125$ minutes.
   $L_q = 4.05$ cars.
   $L_s = 4.95$ cars.

6. *a.* 3 minutes.
   b. 45 seconds.
   c. Yes, about 36 seconds.

7. *a.* 2.08 people.
   b. 2.92 people.
   c. 0.208 hour.
   d. 0.292 hour.
   e. Infinity.

8. *a.* 3 people.
   b. 1 minute.
   c. 75%.
   d. .4219.
   e. Time reduced by 22.5 seconds: avg. no. of people reduced by 1.125.

9. *a.* $L = 4(0.055) = 0.22$ waiting.
   b. $W = 0.466$ hour.
   c. $D = .362$.

16 Customers enter the camera department of a store at the average rate of six per hour. The department is staffed by one employee, who takes an average of six minutes to serve each arrival. Assume this is a simple Poisson arrival, exponentially distributed service time situation.
- *a.* As a casual observer, how many people would you expect to see in the camera department (excluding the clerk)? How long would a customer expect to spend in the camera department (total time)?
- *b.* What is the utilization of the clerk?
- *c.* What is the probability that there are more than two people in the camera department (excluding the clerk)?
- *d.* Another clerk has been hired for the camera department who also takes an average of six minutes to serve each arrival. How long would a customer expect to spend in the department now?

16. *a.* 1.5 people; 15 minutes.
b. 60%.
c. $1 - .784 = .216$.
d. 0.1099 hour.

17 Cathy Livingston, bartender at the Tucson Racquet Club, can serve drinks at the rate of one every 50 seconds. During a hot evening recently, the bar was particularly busy and every 55 seconds someone was at the bar asking for a drink.
- *a.* Assuming that everyone in the bar drank at the same rate and that Cathy served people on a first-come, first-served basis, how long would you expect to have to wait for a drink?
- *b.* How many people would you expect to be waiting for drinks?
- *c.* What is the probability that three or more people are waiting for drinks?
- *d.* What is the utilization of the bartender (how busy is she)?
- *e.* If the bartender is replaced with an automatic drink dispensing machine, how would this change your answer in part *a*?

17. *a.* 9.167 minutes.
b. 9.091 people, or 10 people.
c. .7513.
d. 0.9091; 90.9% of the time.
e. 0.0833 hour or 5.00 minutes.

18 An office employs several clerks who originate documents and one operator who enters the document information in a word processor. The group originates documents at a rate of 25 per hour. The operator can enter the information with average exponentially distributed time of two minutes. Assume the population is infinite, arrivals are Poisson, and queue length is infinite with FCFS discipline.
- *a.* Calculate the percentage utilization of the operator.
- *b.* Calculate the average number of documents in the system.
- *c.* Calculate the average time in the system.
- *d.* Calculate the probability of four or more documents being in the system.
- *e.* If another clerk were added, the document origination rate would increase to 30 per hour. What would this do to the word processor workload? Show why.

18. *a.* 0.833.
b. 5 documents.
c. 0.2 hour.
d. .4822.
e. L_q tends to infinity.

19 A study-aid desk staffed by a graduate student has been established to answer students' questions and help in working problems in your OSM course. The desk is staffed eight hours per day. The dean wants to know how the facility is working. Statistics show that students arrive at a rate of four per hour and the distribution is approximately Poisson. Assistance time averages 10 minutes, distributed exponentially. Assume population and line length can be infinite and queue discipline is FCFS.
- *a.* Calculate the percentage utilization of the graduate student.
- *b.* Calculate the average number of students in the system.
- *c.* Calculate the average time in the system.
- *d.* Calculate the probability of four or more students being in line or being served.
- *e.* Before a test, the arrival of students increases to six per hour on the average. What does this do to the average length of the line?

19. *a.* 0.667.
b. 2 students.
c. 0.5 hour.
d. .1976.
e. $L_q \rightarrow \infty$.

20 At the California border inspection station, vehicles arrive at the rate of 10 per minute in a Poisson distribution. For simplicity in this problem, assume that there is only one lane and one inspector, who can inspect vehicles at the rate of 12 per minute in an exponentially distributed fashion.
- *a.* What is the average length of the waiting line?
- *b.* What is the average time that a vehicle must wait to get through the system?
- *c.* What is the utilization of the inspector?
- *d.* What is the probability that when you arrive there will be three or more vehicles ahead of you?

20. *a.* 4.17 vehicles.
b. $\frac{1}{2}$ minute.
c. 83.3%.
d. $1 - .423 = .5787$.

21 The California border inspection station (see Problem 20) is considering the addition of a second inspector. The vehicles would wait in one lane and then be directed to the first available inspector. Arrival rates would remain the same (10 per minute) and the new inspector would process vehicles at the same rate as the first inspector (12 per minute).
- *a.* What would be the average length of the waiting line?
- *b.* What would be the average time that a vehicle must wait to get through the system?

If a second lane was added (one lane for each inspector):
- *c.* What would be the average length of the waiting line?
- *d.* What would be the average time that a vehicle must wait to get through the system?

21. *a.* 0.175 vehicle.
b. 0.101 minute or 6.06 seconds.
c. 0.596.
d. 0.143 minute or 8.58 seconds.