

Chapter 2

Product, Process, and Schedule Design

SECTION 2.1

- 2.1** Identify the hospital functions and departments to be incorporated in the facilities plan. Identify the key entities for which flow requirements will be needed, e.g., people, paperwork, operating rooms, emergency rooms, vehicular movement, etc. Identify the various criteria that will be used to evaluate the alternative facilities plans generated, e.g. patient service, cleanliness, logic of travel between departments, ease of expansion/updating, cost. Determine the time period over which the facilities requirements will be estimated. Estimate space and flow requirements and determine activity relationships. Generate alternative facilities plans.
- 2.2** It is important for the various design decisions to be integrated so that all critical issues have been considered before product and process designs are finalized. Using a linear or series approach can result in multiple re-starts of the design process because of “down-stream” consequences of “up-stream” design decisions that are made. Overall optimization is the goal, rather than piecewise optimization.

Knowledgeable representatives from each of the activities or functions need to be involved in the design process.

Several concurrent engineering techniques can be used to improve the design process. Quality Function Deployment is one technique that can prove extremely beneficial. However, all of the approaches described in Section 2.5 should receive serious consideration. Since the text is devoted to facilities planning, every technique presented in the text is a candidate for use in a specific application.

- 2.3** Research question. Depending on the comprehensiveness of the collection of periodicals and manuscripts in the university library, it might be more helpful to the students to modify the assignment and encourage them to use the Internet in performing the assigned search.

SECTION 2.2

- 2.4 - 2.6** Research question. Depending on the comprehensiveness of the collection of periodicals and manuscripts in the university library, it might be more helpful to the students to modify the assignment and encourage them to use the Internet in performing the assigned search.

- 2.7** Research question. The Internet will likely be the best source of information needed to answer this question.

SECTION 2.3

- 2.8** The assigned chart submitted for a cheeseburger will vary depending on the assumptions regarding ingredients, e.g., mayonnaise, mustard, catsup, onions, pickles, lettuce, tomato,

multiple beef patties, multiple slices of cheese, intermediate layer of bread. Likewise, the chart submitted for a taco will vary depending on the ingredients included. It is important to verify that the student follows the steps described in Section 2.3.

- 2.9** The assembly chart shows only the operations and inspections associated with the assembly of the product. The operation process chart includes all operations and inspections, fabrication and assembly operations and processing times, and purchased materials.

- 2.10 - 2.11** The solution depends on the recipe chosen.

SECTION 2.4

2.12 $I_1 = 2000 / [(0.92)(0.95)(0.95)(0.97)] = 2,483$ enclosures (rounded to nearest integer)

- 2.13** Given System: (all I_k values are rounded to the nearest integer)

$$I_1 = 1,000 / [0.93(0.95)(0.97)] = 1,167 \text{ units}$$

$$I_2 = 1,000 / [0.93(0.95)] = 1,132 \text{ units}$$

$$I_3 = 1,000 / 0.93 = 1,075 \text{ units}$$

The scrap values and scrap cost at each step are as follows:

$$\text{Process 3: } 1,075 - 1,000 = 75 \text{ units} \rightarrow \text{Scrap Cost} = \$15(75) = \$1,125$$

$$\text{Process 2: } 1,132 - 1,075 = 57 \text{ units} \rightarrow \text{Scrap Cost} = \$10(57) = \$570$$

$$\text{Process 1: } 1,167 - 1,132 = 35 \text{ units} \rightarrow \text{Scrap Cost} = \$5(34) = \$170$$

$$\text{Total Scrap Cost for given system} = \$1,865$$

System w/Reversed Scrap Rates:

$$I_1 = 1,167 \text{ units}$$

$$I_2 = 1,000 / [0.97(0.95)] = 1,085 \text{ units}$$

$$I_3 = 1,000 / 0.97 = 1,031 \text{ units}$$

The scrap values and scrap cost at each step are as follows:

$$\text{Process 3: } 1,031 - 1,000 = 31 \text{ units} \rightarrow \text{Scrap Cost} = \$15(31) = \$465$$

$$\text{Process 2: } 1,085 - 1,031 = 54 \text{ units} \rightarrow \text{Scrap Cost} = \$10(54) = \$540$$

$$\text{Process 1: } 1,167 - 1,085 = 82 \text{ units} \rightarrow \text{Scrap Cost} = \$5(82) = \$410$$

$$\text{Total Scrap Cost for given system} = \$1,415$$

Due to the lower scrap cost the system with reversed scrap rates would be preferred, which is consistent with the claim made in Section 2.4.2.

- 2.14** For simplicity the rework operations are indicated by Rk. All I_k values are rounded to the nearest integer.

Given system: Following the derivation method given in Section 2.4.2.2, we have the expression for I_1 :

$$I_1 = \frac{O_3}{[(1 - d_3) + d_3(1 - d_{R3})][(1 - d_2) + d_2(1 - d_{R2})][(1 - d_1) + d_1(1 - d_{R1})]}$$

$$I_1 = 1,000 / [(0.93 + (0.8)(0.07)][0.95 + (0.75)(0.05)][0.97 + (0.60)(0.03)]]$$

$$I_1 = 1040 \text{ units}$$

To find the rework cost we need only the required input to each rework process. Thus,

$$I_{R1} = I_1(d_1) = 1,040(0.03) = 31 \text{ units}$$

$$I_{R2} = I_1(d_2)[(1 - d_1) + d_1(1 - d_{R1})] = 1,040(0.05)(0.988)$$

$$= 51 \text{ units}$$

$$I_{R3} = I_1(d_3)[(1 - d_2) + d_2(1 - d_{R2})]$$

$$I_{R3} = 1,040(0.07)(0.988)(0.9875) = 71 \text{ units}$$

Therefore, the total rework cost = \$2(31) + \$3(51) + \$4(71) = \$499.

System w/Reversed Scrap Rates: Using the same derivation, we have the following:

$$I_1 = 1,000 / [(0.97 + (0.8)(0.03)][0.95 + (0.75)(0.05)][0.93 + (0.60)(0.07)]]$$

$$I_1 = 1048 \text{ units}$$

$$I_{R1} = 1,048(0.07) = 73 \text{ units}$$

$$I_{R2} = 1,048(0.05)(0.972) = 51 \text{ units}$$

$$I_{R3} = 1,048(0.03)(0.972)(0.9875) = 30 \text{ units}$$

Therefore, the total rework cost for the system with the reversed scrap rates = \$2(73) + \$3(51) + \$4(30) = \$419.

Based solely on the total rework costs of the two systems, the system with reversed scrap rates is preferred, which is consistent with the result of Problem 2.13. You should note, however, that the system with reversed scrap rates requires more input to the system to meet the demand.

- 2.15** All I_k values are rounded to the nearest integer.

$$I_B = Q_B = O_B / (1 - d_B) = 3,000 / 0.95 = 3,158 \text{ units}$$

$$I_A = Q_A = O_B / [(1 - d_B)(1 - d_A)] = 3,000 / [0.95(0.98)] = 3,222 \text{ units}$$

$$F = S_A(Q_A) / [(E_A)(H)(R_A)] + S_B(Q_B) / [(E_B)(H)(R_B)] + [30(Q_A / 500)] / H$$

$$H = 5 \text{ days/week}(18 \text{ hours/day})(60 \text{ min/hr}) = 5,400 \text{ min/week}$$

$$F = 3(3,222) / [(0.95)(5,400)(0.95)] + 5(3,158) / [(0.95)(5,400)(0.90)]$$

$$+ [30(3,222 / 500)] / 5,400$$

$$F = 5.439 \approx 6 \text{ milling machines}$$

- 2.16** We solve this problem working in reverse.

$$\begin{aligned}O_1 &= (1 - d_1)I_1 \\O_2 &= (1 - d_2)(1 - d_1)I_1 \\I_4 &= d_2(1 - d_1)I_1 \\O_4 &= (1 - d_4)(d_2)(1 - d_1)I_1 \\I_3 &= O_2 + O_4 = [(1 - d_2)(1 - d_1) + (1 - d_4)(1 - d_1)d_2]I_1 \\O_3 &= (1 - d_3)[(1 - d_2)(1 - d_1) + (1 - d_4)(1 - d_1)d_2]I_1\end{aligned}$$

Solving for I_1 and substituting in the appropriate parameters, we have the following:

$$\begin{aligned}I_1 &= 5,000 / (0.90)[(0.95)(0.95) + (0.98)(0.95)(0.5)] \\I_1 &= 5,854 \text{ units (rounded to nearest integer)}\end{aligned}$$

- 2.17** All I_k values rounded to the nearest integer. For machines 1, 2, and 3:
 $H = (16 \text{ hours/day})(60 \text{ mins/hour})(5 \text{ days/week}) = 4,800 \text{ mins/week}$
Machine 4 operates for half of the amount of time as machines 1, 2, and 3.

We know that $I_k = Q_k$. So,

$$\begin{aligned}F_1 &= Q_1(S_1)/[(H)(E_1)(R_2)] \\F_1 &= (5,854)(3)/[(4,800)(1)(0.95)] = 3.85 \approx 4 \text{ machines}\end{aligned}$$

$$\begin{aligned}I_2 &= (1 - d_1)I_1 = 0.95(5,854) = 5,561 \text{ units} \\F_2 &= (5,561)(2)/[(4,800)(0.95)(0.90)] = 2.71 \approx 3 \text{ machines}\end{aligned}$$

$$\begin{aligned}I_3 &= O_3/(1 - d_3) = 5,000/0.90 = 5,556 \text{ units} \\F_2 &= (5,556)(5)/[(4,800)(1.02)(0.90)] = 6.3 \approx 7 \text{ machines}\end{aligned}$$

$$\begin{aligned}I_4 &= d_2 O_1 = 0.05(0.95)(5,584) = 278 \text{ units} \\F_4 &= (278)(10)/[(2,400)(0.90)(0.95)] = 1.35 \approx 2 \text{ machines}\end{aligned}$$

Running the rework operation on the same shift as the remainder of the cell would cause the machine fraction to reduce to 0.68, or 1 machine. This may allow for the addition of the rework machine to the cell.

- 2.18** All I_k values rounded to nearest integer. Let A1 denote the first step in the production process, and A2 denote the last step.

$$\begin{aligned}I_{A1} &= O_3 / [(1 - d_3)(1 - d_2)(1 - d_1)] \\I_{A1} &= 10,000 / [(0.95)(0.95)(0.97)] = 11,423 \text{ units}\end{aligned}$$

Similarly,

$$\begin{aligned}I_B &= 10,000 / [(0.95)(0.97)] = 10,080 \text{ units} \\I_{A2} &= 10,000 / [0.95] = 10,526 \text{ units}\end{aligned}$$

$$H = (8 \text{ hours/day})(60 \text{ mins/hour})(6 \text{ days/week}) = 2,880 \text{ mins/week}$$

We know that $I_k = Q_k$. So,

$$\begin{aligned} F_A &= Q_{A1}(S_{A1})/[(H)(E_{A1})(R_{A1})] + Q_{A2}(S_{A2})/[(H)(E_{A2})(R_2)] \\ F_A &= (11,423)(5)/[(2,880)(1.08)(0.98)] + (10,526)(3)/[(2,880)(0.90)(0.95)] \\ F_A &= 31.57 \approx 32 \text{ machines} \end{aligned}$$

$$\begin{aligned} F_B &= Q_B(S_B)/[(H)(E_B)(R_B)] \\ F_B &= (11,080)(5)/[(2,880)(1.08)(0.98)] = 12.79 \approx 13 \text{ machines} \end{aligned}$$

- 2.19** All I_k values are rounded to the nearest integer.

$$\begin{aligned} I_{XC} &= O_X/[1 - d_{XC}] = 100,000/0.97 = 103,093 \text{ units} \\ I_{XB} &= O_X/[(1 - d_{XC})(1 - d_{XB})] \\ I_{XB} &= 100,000/[(0.97)(0.96)] = 107,388 \text{ units} \\ I_{XA} &= O_X/[(1 - d_{XC})(1 - d_{XB})(1 - d_{XA})] \\ I_{XA} &= 100,000/[(0.97)(0.96)(0.95)] = 113,040 \text{ units} \end{aligned}$$

$$\begin{aligned} I_{YC} &= O_Y/[1 - d_{YC}] = 200,000/0.97 = 206,186 \text{ units} \\ I_{YA} &= O_Y/[(1 - d_{YC})(1 - d_{YA})] \\ I_{YA} &= 200,000/[(0.97)(0.95)] = 217,037 \text{ units} \\ I_{YB} &= O_Y/[(1 - d_{YC})(1 - d_{YA})(1 - d_{YB})] \\ I_{YB} &= 200,000/[(0.97)(0.95)(0.96)] = 226,081 \text{ units} \end{aligned}$$

Setup times are identical for machines A, B, and C for a particular product. The setup time for product X, regardless of the machine, is 20 mins; the setup time for product Y is 40 mins., regardless of the machine. A critical piece of information needed to determine the number of machines required is the length of production runs between setups. If a single setup is needed to produce the annual requirement of a product on a machine, then the number of machines required is determined as follows:

$$\begin{aligned} F_A &= \frac{0.15(113,040)}{(0.85)(1600)(0.95)} + \frac{0.15(217,037)}{(0.85)(1600)(0.95)} + \frac{20 + 40}{(60)(1600)} \\ F_A &= 13.12 + 16.8 + 0.00065 = 29.92 \approx 30 \text{ machines} \end{aligned}$$

$$\begin{aligned} F_B &= \frac{0.25(107,388)}{(0.90)(1600)(0.90)} + \frac{0.25(226,081)}{(0.90)(1600)(0.90)} + \frac{20 + 40}{(60)(1600)} \\ F_B &= 20.72 + 17.44 + 0.00065 = 38.16 \approx 39 \text{ machines} \end{aligned}$$

$$\begin{aligned} F_C &= \frac{0.15(103,093)}{(0.95)(1600)(0.85)} + \frac{0.15(206,186)}{(0.95)(1600)(0.85)} + \frac{20 + 40}{(60)(1600)} \\ F_C &= 7.98 + 23.94 + 0.00065 = 31.92 \approx 32 \text{ machines} \end{aligned}$$

If setups occur more frequently, then additional machines might be required due to the lost production time consumed by setups.

- 2.20** All I_k values are rounded to the nearest integer.

$$\text{Part A: } I_1 = O_6 / [(1 - d_6)(1 - d_4)(1 - d_2)(1 - d_1)] \\ I_1 = 15,000 / [(0.70)(0.85)(0.90)(0.80)] = 35,014 \text{ units}$$

$$\text{Part B: } I_3 = 3 * I_4 / (1 - d_3) \\ I_4 = O_6 / [(1 - d_6)(1 - d_3)] = 15,000 / [(0.70)(0.85)] = 25,210 \\ \text{Then, } I_3 = (3 * 25,210) / 0.70 = 108,043 \text{ units}$$

$$\text{Part C: } I_5 = O_6 / [(1 - d_6)(1 - d_5)] = 15,000 / [(0.70)(0.75)] = 28,571 \text{ units}$$

- 2.21** Using the equations to solve Problem 2.20, we simply change the input values. Let d'_k represent the new scrap percentage. For this solution, we are assuming the 5% reduction is as follows: $d'_k \rightarrow d_k - 0.05$. You could also view the problem statement as indicating that $d'_k \rightarrow 0.95 * d_k$. All I_k values are rounded to the nearest integer.

$$\text{Part A: } I_1 = 15,000 / [(0.75)(0.90)(0.95)(0.85)] = 27,520 \text{ units} \\ \text{This represents a 21.4\% reduction in the input requirement.}$$

$$\text{Part B: } I_4 = 15,000 / [(0.75)(0.90)] = 22,222 \\ I_3 = (3 * 22,222) / 0.75 = 88,888 \text{ units} \\ \text{This represents a 17.7\% reduction in the input requirement.}$$

$$\text{Part C: } I_4 = 15,000 / [(0.75)(0.80)] = 25,000 \text{ units} \\ \text{This represents a 12.5\% reduction in the input requirement.}$$

The opinion response will depend on the student. However, the response should look something like the following.

Estimation Perspective: For most tasks that a process designer may have to plan for there are likely to be many alternatives. The designer must be able to identify the issues related to each alternative and be able to generate an accurate estimate of the scrap rate. Even in the case where there may be only a single alternative the ability to accurately estimate the scrap rate is of great significance.

Continuous Improvement Perspective: Being able to reduce the scrap produced by a process can be shown to significantly reduce the input requirement to a process.

- 2.22** The value of H is up to the student or instructor. Any value will provide sufficient illustration for the follow-up opinion question. For the purposes of this solution, we will assume H is a variable value and solve symbolically.

Before reduction: $I_4 = Q_4 = 25,210$. Thus,

$$F_4 = S_4 Q_4 / [H E_4 R_4] = (4 * 25,210) / [(H)(0.95)(0.98)] = 108,313.64/H$$

After reduction: $I_4 = Q_4 = 22,222$. Thus,

$$F_4 = S_4 Q_4 / [H E_4 R_4] = (4 * 22,222) / [(H)(0.95)(0.98)] = 95,475.83/H$$

It should be apparent that by reducing the scrap percentage will reduce the number of machines necessary. Assuming one 8 hour shift per day, 5 days per week, reducing the scrap percentage as indicated in Problem 2.21 would result in a reduction of 6 machines. This could be a significant reduction in the floor space required to perform a specific process. In addition, reduction of the input needed for a specific process may also reduce the amount of storage space for raw materials/WIP, further reducing floor space requirements. For the facilities planner, space is at a premium, so every advantage should be taken to either improve processes or select processes that produce less scrap.

- 2.23** $I = Q = 0 / (1 - d) = 750 / 0.80 = 938$ units (rounded to nearest integer)

$$F = SQ/EHR = [(1/4)(938)] / [(15/20)(7)(0.75)] = 44.67 \approx 45 \text{ machines}$$

Alternatively, you could say that the loss of one hour per shift is a reduction in the reliability. Thus, the denominator would have the following: $H = 8$, $R = 7/8$.

- 2.24** Let CA, CB, B, F, FA, IN, and M represent component A, component B, blanking, forging, final assembly, inspection, and machining, respectively. Let O_{SA} = Amount of demand for spare parts of Component A = 1,000 units; and I_{FA} = Input needed for final assembly for Component A. All I_k values are rounded to the nearest integer.

$$I_{FA} = 2(O_{FA} / (1 - d_{FA})) = 2(5,000 / 0.95) = 10,526 \text{ units}$$

$$I_{CA} = (O_S + I_{FA}) / [(1 - d_M)(1 - d_F)(1 - d_B)]$$

$$I_{CA} = (1,000 + 10,526) / [(0.75)(0.85)(0.90)] = 20,089 \text{ units}$$

$$I_{CB} = O_{FA} / [(1 - d_{FA})(1 - d_{IN})] = 5,000 / [(0.95)(0.98)] = 5,371 \text{ units}$$

- 2.25** $I_1 = [O_6 / ((1 - d_6)(1 - d_5)(1 - d_4)(1 - d_3)(1 - d_2)(1 - d_1))]$

Where $[xx]$ stands for the least integer $\geq xx$.

- 2.26** Let BC, BY, CB, DA, IN, KP, and TC represent the bottom cover, battery cover, circuit board, disassembly, inspection, keypad, and top cover, respectively. In addition, let M_{xx} represent molding operations for specific components; P_{xx} represent painting operations for specific components; and IN_x represent inspection stations in order of occurrence. All I_k values are rounded to the nearest integer.

$$I_{TC} = 0 / [(1 - d_{MTC})(1 - d_{PTC})] = 10,000 / [(0.95)(0.95)] = 11,080 \text{ units}$$

$$I_{KP} = 0 / [(1 - d_{MKP})(1 - d_{PKP})] = 10,000 / [(0.98)(0.95)] = 10,741 \text{ units}$$

$$I_{BY} = 0/(1 - d_{MBY}) = 10,000/0.92 = 10,870 \text{ units}$$

$$I_{CB} = 0/[(1 - d_{IN1})(1 - d_{IN2})] = 10,000/[(0.97)(0.90)] = 11,455 \text{ units}$$

To find the number of units of the bottom cover to mold, we'll assume that it only goes through the inspection process once.

$$I_{IN2} = (1 - d_{MBC})I_{BC}$$

$$O_{IN2} = (1 - d_{IN2})I_{IN2} = (1 - d_{IN2})(1 - d_{MBC})I_{BC}$$

$$O_{DA} = d_{IN2}I_{IN2}(1 - d_{DA}) = (1 - d_{MBC})d_{IN2}(1 - d_{DA})I_{BC}$$

$$\text{Thus, } O = (1 - d_{IN2})(1 - d_{MBC})I_{BC} + (1 - d_{MBC})d_{IN2}(1 - d_{DA})I_{BC}$$

$$I_{BC} = 0/[(1 - d_{IN2})(1 - d_{MBC}) + (1 - d_{MBC})(d_{IN2})(1 - d_{DA})]$$

$$I_{BC} = 10,000/[(0.97)(0.90) + (0.90)(0.03)(0.25)] = 11,367 \text{ units}$$

- 2.27** Shown below is the probability mass function for number of good castings produced (x), based on Q castings scheduled for production.

# Good Castings	Number of Castings Scheduled										
	20	21	22	23	24	25	26	27	28	29	30
12	0.10	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.10	0.10	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00
14	0.10	0.10	0.10	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00
15	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.00	0.00	0.00	0.00
16	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.05	0.00	0.00	0.00
17	0.10	0.10	0.10	0.10	0.10	0.05	0.05	0.05	0.05	0.00	0.00
18	0.20	0.10	0.10	0.10	0.10	0.05	0.05	0.10	0.05	0.05	0.05
19	0.10	0.15	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.05	0.05
20	0.10	0.10	0.15	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.05
21	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
22	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
23	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10
24	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10
25	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10
26	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.10	0.10	0.10
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.10	0.10
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05
29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05

Shown below is the matrix of net income for each combination of Q and x .

# Good Castings	Number of Castings Scheduled										
	20	21	22	23	24	25	26	27	28	29	30
12	-\$8,000	-\$8,400	-\$8,800	-\$9,200	-\$9,600	-\$10,000	-\$10,400	-\$10,800	-\$11,200	-\$11,600	-\$12,000
13	-\$8,000	-\$8,400	-\$8,800	-\$9,200	-\$9,600	-\$10,000	-\$10,400	-\$10,800	-\$11,200	-\$11,600	-\$12,000
14	-\$8,000	-\$8,400	-\$8,800	-\$9,200	-\$9,600	-\$10,000	-\$10,400	-\$10,800	-\$11,200	-\$11,600	-\$12,000
15	-\$8,000	-\$8,400	-\$8,800	-\$9,200	-\$9,600	-\$10,000	-\$10,400	-\$10,800	-\$11,200	-\$11,600	-\$12,000
16	-\$8,000	-\$8,400	-\$8,800	-\$9,200	-\$9,600	-\$10,000	-\$10,400	-\$10,800	-\$11,200	-\$11,600	-\$12,000
17	-\$8,000	-\$8,400	-\$8,800	-\$9,200	-\$9,600	-\$10,000	-\$10,400	-\$10,800	-\$11,200	-\$11,600	-\$12,000
18	-\$8,000	-\$8,400	-\$8,800	-\$9,200	-\$9,600	-\$10,000	-\$10,400	-\$10,800	-\$11,200	-\$11,600	-\$12,000
19	-\$8,000	-\$8,400	-\$8,800	-\$9,200	-\$9,600	-\$10,000	-\$10,400	-\$10,800	-\$11,200	-\$11,600	-\$12,000
20	\$16,000	\$15,600	\$15,200	\$14,800	\$14,400	\$14,000	\$13,600	\$13,200	\$12,800	\$12,400	\$12,000
21	\$0	\$16,300	\$15,900	\$15,500	\$15,100	\$14,700	\$14,300	\$13,900	\$13,500	\$13,100	\$12,700
22	\$0	\$0	\$16,600	\$16,200	\$15,800	\$15,400	\$15,000	\$14,600	\$14,200	\$13,800	\$13,400
23	\$0	\$0	\$0	\$16,200	\$15,800	\$15,400	\$15,000	\$14,600	\$14,200	\$13,800	\$13,400
24	\$0	\$0	\$0	\$0	\$15,800	\$15,400	\$15,000	\$14,600	\$14,200	\$13,800	\$13,400
25	\$0	\$0	\$0	\$0	\$0	\$15,400	\$15,000	\$14,600	\$14,200	\$13,800	\$13,400
26	\$0	\$0	\$0	\$0	\$0	\$0	\$15,000	\$14,600	\$14,200	\$13,800	\$13,400
27	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$14,600	\$14,200	\$13,800	\$13,400
28	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$14,200	\$13,800	\$13,400
29	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$13,800	\$13,400
30	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$13,400

For a given value of Q, multiplying the net income in the column by the probability of its occurrence and summing over all values of x yields the following expected profits for each value of Q.

Expected Profit											
Number of Castings Scheduled											
20	21	22	23	24	25	26	27	28	29	30	
-\$5,600	-\$3,530	-\$190	\$750	\$2,890	\$5,030	\$5,900	\$6,770	\$8,910	\$11,050	\$10,720	

Based on the results obtained, scheduling 29 castings for production yields the maximum expected profit of \$11,050.

- 2.28** Shown below is the probability mass function for number of good castings produced (x), based on Q castings scheduled for production.

# Good Castings	Number of Castings Scheduled														
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
5	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
7	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
8	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.10	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
12	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00	0.00
14	0.15	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00
15	0.20	0.15	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00	0.00
16	0.00	0.20	0.15	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00
17	0.00	0.00	0.20	0.15	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00	0.00
18	0.00	0.00	0.00	0.20	0.15	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.00	0.00	0.00
19	0.00	0.00	0.00	0.00	0.20	0.15	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.00	0.00
20	0.00	0.00	0.00	0.00	0.00	0.20	0.15	0.10	0.10	0.05	0.05	0.05	0.05	0.05	0.05
21	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.15	0.10	0.10	0.05	0.05	0.05	0.05	0.05
22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.15	0.10	0.10	0.05	0.05	0.05	0.05
23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.15	0.15	0.10	0.05	0.05	0.05
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.15	0.15	0.10	0.05	0.05
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.15	0.15	0.10	0.05
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.15	0.15	0.10
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.15	0.10
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.15
29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20

Shown below is the matrix of net income for each combination of Q and x.

# Good Castings	Number of Castings Scheduled															
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
5	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	\$10,450	-\$10,925	\$11,400	-\$11,875	\$12,350	-\$12,825	-\$13,300	-\$13,775	\$14,250
6	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	\$10,450	-\$10,925	\$11,400	-\$11,875	\$12,350	-\$12,825	-\$13,300	-\$13,775	\$14,250
7	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	\$10,450	-\$10,925	\$11,400	-\$11,875	\$12,350	-\$12,825	-\$13,300	-\$13,775	\$14,250
8	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	\$10,450	-\$10,925	\$11,400	-\$11,875	\$12,350	-\$12,825	-\$13,300	-\$13,775	\$14,250
9	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	\$10,450	-\$10,925	\$11,400	-\$11,875	\$12,350	-\$12,825	-\$13,300	-\$13,775	\$14,250
10	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	\$10,450	-\$10,925	\$11,400	-\$11,875	\$12,350	-\$12,825	-\$13,300	-\$13,775	\$14,250
11	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	\$10,450	-\$10,925	\$11,400	-\$11,875	\$12,350	-\$12,825	-\$13,300	-\$13,775	\$14,250
12	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	\$10,450	-\$10,925	\$11,400	-\$11,875	\$12,350	-\$12,825	-\$13,300	-\$13,775	\$14,250
13	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	\$10,450	-\$10,925	\$11,400	-\$11,875	\$12,350	-\$12,825	-\$13,300	-\$13,775	\$14,250
14	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	\$10,450	-\$10,925	\$11,400	-\$11,875	\$12,350	-\$12,825	-\$13,300	-\$13,775	\$14,250
15	\$8,025	\$8,150	\$8,075	\$8,200	\$8,025	\$8,250	\$8,775	\$8,300	\$8,825	\$8,350	\$8,875	\$8,400	\$8,925	\$8,450	\$8,975	\$10,500
16	\$0	\$9,200	\$8,725	\$8,250	\$7,775	\$7,300	\$6,825	\$6,300	\$6,875	\$6,400	\$6,925	\$6,450	\$6,975	\$6,500	\$6,725	\$8,500
17	\$0	\$0	\$9,775	\$9,300	\$8,825	\$8,350	\$7,875	\$7,400	\$8,925	\$8,450	\$8,975	\$8,500	\$8,025	\$8,550	\$8,725	\$8,000
18	\$0	\$0	\$0	\$10,350	\$9,875	\$9,300	\$8,925	\$8,450	\$7,975	\$7,500	\$8,025	\$8,550	\$8,075	\$8,625	\$8,725	\$9,000
19	\$0	\$0	\$0	\$0	\$10,925	\$10,450	\$9,975	\$9,500	\$9,025	\$8,550	\$8,175	\$8,725	\$8,200	\$8,775	\$8,725	\$9,700
20	\$0	\$0	\$0	\$0	\$0	\$11,500	\$11,015	\$10,550	\$10,075	\$9,600	\$9,125	\$8,650	\$8,175	\$7,700	\$7,225	\$8,700
21	\$0	\$0	\$0	\$0	\$0	\$0	\$11,015	\$10,550	\$10,075	\$9,600	\$9,125	\$8,650	\$8,175	\$7,700	\$7,225	\$8,700
22	\$0	\$0	\$0	\$0	\$0	\$0	\$10,550	\$10,075	\$9,600	\$9,125	\$8,650	\$8,175	\$7,700	\$7,225	\$8,700	\$8,700
23	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$10,075	\$9,600	\$9,125	\$8,650	\$8,175	\$7,700	\$7,225	\$8,700	\$8,700
24	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$9,600	\$9,125	\$8,650	\$8,175	\$7,700	\$7,225	\$8,700	\$8,700
25	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$9,125	\$8,650	\$8,175	\$7,700	\$7,225	\$8,700	\$8,700
26	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$8,650	\$8,175	\$7,700	\$7,225	\$8,700	\$8,700
27	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$8,175	\$7,700	\$7,225	\$8,700	\$8,700
28	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$7,700	\$7,225	\$8,700	\$8,700
29	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$7,225	\$8,700	\$8,700
30	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$6,700

For a given value of Q, multiplying the net income in the column by the probability of its occurrence and summing over all values of x yields the following expected profits for each value of Q.

Expected Profit Number of Castings Scheduled															
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
\$8,975	\$1,878	\$3,788	\$3,003	\$3,733	\$4,780	\$5,470	\$6,455	\$7,135	\$7,763	\$8,338	\$8,121	\$7,860	\$7,543	\$7,173	\$6,750

Based on the results obtained, scheduling 25 castings for production yields the maximum expected profit of \$8,338.

- 2.29** Shown below is the probability mass function for number of good castings produced (x), based on Q castings scheduled for production.

# Good Castings	Number of Castings Scheduled														
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
7	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
8	0.0008	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
9	0.0047	0.0013	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
10	0.0208	0.0067	0.0019	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0.0094	0.0206	0.0091	0.0028	0.0008	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0.1690	0.0814	0.0332	0.0120	0.0039	0.0012	0.0003	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	0.2870	0.1837	0.0937	0.0405	0.0154	0.0053	0.0017	0.0005	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
14	0.3006	0.2886	0.1963	0.1060	0.0483	0.0193	0.0070	0.0023	0.0007	0.0002	0.0001	0.0000	0.0000	0.0000	0.0000
15	0.1470	0.2822	0.1878	0.2012	0.1181	0.0617	0.0238	0.0090	0.0031	0.0010	0.0003	0.0001	0.0000	0.0000	0.0000
16	0.00	0.1293	0.1638	0.2850	0.2166	0.1199	0.0655	0.0288	0.0114	0.0041	0.0014	0.0004	0.0001	0.0000	0.0000
17	0.00	0.00	0.1138	0.2458	0.2803	0.2142	0.1413	0.0746	0.0343	0.0141	0.0053	0.0018	0.0006	0.0001	0.0000
18	0.00	0.00	0.00	0.1002	0.2284	0.2140	0.1302	0.1519	0.0839	0.0403	0.0173	0.0067	0.0024	0.0008	0.0003
19	0.00	0.00	0.00	0.00	0.0881	0.2115	0.1665	0.2345	0.1618	0.0932	0.0466	0.0208	0.0084	0.0031	0.0011
20	0.00	0.00	0.00	0.00	0.00	0.0776	0.1955	0.2980	0.2374	0.1700	0.1025	0.0533	0.0347	0.0104	0.0040
21	0.00	0.00	0.00	0.00	0.00	0.0683	0.1802	0.2487	0.2887	0.1790	0.1117	0.0603	0.0290	0.0126	0.0050
22	0.00	0.00	0.00	0.00	0.00	0.0601	0.1658	0.2387	0.2397	0.1862	0.1307	0.0676	0.0336	0.0151	0.0051
23	0.00	0.00	0.00	0.00	0.00	0.00	0.0529	0.1522	0.2263	0.2375	0.1924	0.1293	0.0750	0.0366	0.0166
24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0463	0.1393	0.2177	0.2331	0.1971	0.1374	0.0823	0.0401
25	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0409	0.1277	0.2069	0.2317	0.2016	0.1451	0.0841
26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0360	0.1107	0.1961	0.2274	0.2047	0.1427
27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0317	0.1063	0.1853	0.2224	0.1747
28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0279	0.0971	0.1747	0.2224	0.1747
29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0245	0.0884	0.1747
30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0216

Net incomes for feasible combinations of Q and x are shown below.

# Good Castings	Number of Castings Scheduled															
	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
1	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
2	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
3	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
4	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
5	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
6	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
7	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
8	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
9	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
10	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
11	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
12	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
13	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
14	-\$7,125	-\$7,600	-\$8,075	-\$8,550	-\$9,025	-\$9,500	-\$9,975	-\$10,450	-\$10,925	-\$11,400	-\$11,875	-\$12,350	-\$12,825	-\$13,300	-\$13,775	-\$14,250
15	\$19,300	\$19,500	\$19,500	\$19,500	\$19,500	\$19,500	\$19,500	\$19,500	\$19,500	\$19,500	\$19,500	\$19,500	\$19,481	\$19,436	\$19,389	\$19,347
16	\$0	\$20,800	\$20,800	\$20,800	\$20,800	\$20,800	\$20,800	\$20,800	\$20,800	\$20,800	\$20,800	\$20,800	\$20,781	\$20,736	\$20,689	\$20,647
17	\$0	\$0	\$22,100	\$22,100	\$22,100	\$22,100	\$22,100	\$22,100	\$22,100	\$22,100	\$22,100	\$22,100	\$22,081	\$22,036	\$21,989	\$21,947
18	\$0	\$0	\$0	\$23,400	\$23,400	\$23,400	\$23,400	\$23,400	\$23,400	\$23,400	\$23,400	\$23,400	\$23,381	\$23,336	\$23,289	\$23,247
19	\$0	\$0	\$0	\$0	\$24,700	\$24,700	\$24,700	\$24,700	\$24,700	\$24,700	\$24,700	\$24,700	\$24,681	\$24,636	\$24,589	\$24,547
20	\$0	\$0	\$0	\$0	\$0	\$26,000	\$26,000	\$26,000	\$26,000	\$26,000	\$26,000	\$26,000	\$25,981	\$25,936	\$25,889	\$25,847
21	\$0	\$0	\$0	\$0	\$0	\$0	\$11,025	\$10,550	\$10,075	\$9,600	\$9,125	\$8,650	\$8,175	\$7,700	\$7,221	\$6,750
22	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$10,550	\$10,075	\$9,600	\$9,125	\$8,650	\$8,175	\$7,700	\$7,221	\$6,750
23	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$10,075	\$9,600	\$9,125	\$8,650	\$8,175	\$7,700	\$7,221	\$6,750
24	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$9,600	\$9,125	\$8,650	\$8,175	\$7,700	\$7,221	\$6,750
25	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$9,125	\$8,650	\$8,175	\$7,700	\$7,221	\$6,750
26	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$8,650	\$8,175	\$7,700	\$7,221	\$6,750
27	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$8,175	\$7,700	\$7,221	\$6,750
28	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$7,700	\$7,221	\$6,750
29	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$7,221	\$6,750
30	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$6,750

For a given value of Q, multiplying the net income in the column by the probability of its occurrence and summing over all values of x yields the following expected profits for each value of Q. Based on the results obtained, scheduling 21 castings for production yields the maximum expected profit of \$22,663.

Expected Profit															
Number of Castings Scheduled															
15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
-\$3,212	\$3,721	\$10,915	\$16,362	\$19,904	\$22,170	\$22,663	\$20,984	\$17,885	\$14,933	\$11,914	\$10,038	\$8,800	\$7,958	\$7,324	\$6,785

- 2.30a** Shown below is the probability mass function for the number of good custom-designed castings produced (x), based on Q castings scheduled for production.

# Good Castings	Number of Castings Scheduled			
	4	5	6	7
0	0.0001	0.0000	0.0000	0.0000
1	0.0036	0.0005	0.0001	0.0000
2	0.0486	0.0081	0.0012	0.0002
3	0.2916	0.0729	0.0146	0.0026
4	0.6361	0.3281	0.0984	0.0230
5	0.0000	0.5905	0.3143	0.1240
6	0.0000	0.0000	0.5114	0.3720
7	0.0000	0.0000	0.0000	0.4783

Net incomes for feasible combinations of Q and x are shown below.

# Good Castings	Number of Castings Scheduled			
	4	5	6	7
0	-\$60,000	-\$75,000	-\$90,000	-\$105,000
1	-\$60,000	-\$75,000	-\$90,000	-\$105,000
2	-\$60,000	-\$75,000	-\$90,000	-\$105,000
3	-\$60,000	-\$75,000	-\$90,000	-\$105,000
4	\$60,000	\$45,000	\$30,000	\$15,000
5	\$0	\$45,000	\$30,000	\$15,000
6	\$0	\$0	\$30,000	\$15,000
7	\$0	\$0	\$0	\$15,000

For a given value of Q, multiplying the net income in the column by the probability of its occurrence and summing over all values of x yields the following expected profits for each value of Q. As shown, the optimum number to schedule is 5, with an expected net profit of \$35,225.

Expected Profit			
Number of Castings Scheduled			
4	5	6	7
\$18,732	\$35,225	\$28,098	\$14,673

- 2.30b** The probability of losing money on the transaction is the probability of the net income being negative when Q equals 5. From above, a negative net cash flow occurs if less than 4 good castings are produced. The probability of producing less than 4 good castings equals $0.0005 + 0.0081 + 0.0729$, or 0.0815.
- 2.30c** Using Excel it is easy to perform the sensitivity analysis. By varying the cost parameter, it is found that a cost of \$22,044.96 yields an expected profit of zero for Q = 5. Likewise, when the cost of producing a casting is reduced to \$7,873.19, the optimum number to schedule increases to 6. We could not find a cost that would reduce the optimum production batch to 4 and still have a positive expected profit.
- 2.30d** Again, using Excel it is easy to perform sensitivity analyses. For example, if the probability of a good casting is reduced to 0.84248 then the optimum production batch increases to 6; likewise, if the probability of a good casting increases to 0.963781, then the optimum batch production quantity decreases to 4.
- 2.31** Shown below is the probability mass function for number of good high precision formed parts (x), based on Q parts scheduled for production.

# Good Parts	Number Scheduled		
	10	11	12
0	0.0000	0.0000	0.0000
1	0.0000	0.0000	0.0000
2	0.0000	0.0000	0.0000
3	0.0001	0.0000	0.0000
4	0.0012	0.0003	0.0001
5	0.0085	0.0023	0.0006
6	0.0401	0.0132	0.0040
7	0.1298	0.0536	0.0193
8	0.2759	0.1517	0.0683
9	0.3474	0.2866	0.1720
10	0.1969	0.3248	0.2924
11	0.00	0.1673	0.3012
12	0.00	0.00	0.1422
13	0.00	0.00	0.00

Shown below is the matrix of net income for batch sizes of 10, 11, and 12. Also shown below is the expected profit based on batch sizes of 10, 11, and 12, as well as the probability of losing money. A batch size of 12 yields the smallest expected profit. Based on the probability of losing money, the least attractive alternative is a batch size of 10.

# Good Castings	Number Scheduled		
	10	11	12
0	-\$4,750	-\$5,225	-\$5,700
1	-\$4,750	-\$5,225	-\$5,700
2	-\$4,750	-\$5,225	-\$5,700
3	-\$4,750	-\$5,225	-\$5,700
4	-\$4,750	-\$5,225	-\$5,700
5	-\$4,750	-\$5,225	-\$5,700
6	-\$4,750	-\$5,225	-\$5,700
7	-\$4,750	-\$5,225	-\$5,700
8	\$150,000	\$85,000	\$20,000
9	\$250,000	\$185,000	\$120,000
10	\$350,000	\$285,000	\$220,000
11	\$0	\$285,000	\$220,000
12	\$0	\$0	\$220,000
13	\$0	\$0	\$0

Expected Profit and Probability of Losing Money		
10	11	12
\$196,293	\$205,834	\$183,746
0.1798	0.0694	0.0239

- 2.32 Shown below is the probability mass function for the number of good wafers (x) resulting from a production batch size of Q.

# Good Wafers	Number of Wafers Scheduled						
	4	5	6	7	8	9	10
0	0.0039	0.0010	0.0002	0.0001	0.0000	0.0000	0.0000
1	0.0469	0.0146	0.0044	0.0013	0.0004	0.0001	0.0000
2	0.2109	0.0879	0.0330	0.0113	0.0038	0.0012	0.0004
3	0.4219	0.2637	0.1318	0.0577	0.0231	0.0087	0.0031
4	0.3164	0.3955	0.2966	0.1730	0.0865	0.0389	0.0162
5	0.0000	0.2373	0.3360	0.3113	0.2076	0.1168	0.0584
6	0.0000	0.0000	0.1780	0.3113	0.3115	0.2336	0.1460
7	0.0000	0.0000	0.0000	0.1333	0.2670	0.3003	0.2503
8	0.0000	0.0000	0.0000	0.0000	0.1001	0.1253	0.2816
9	0.0000	0.0000	0.0000	0.0000	0.0000	0.0751	0.1877
10	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0363

Shown below is the matrix of net profit resulting from combinations of Q and x.

# Good Wafers	Number of Wafers Scheduled						
	4	5	6	7	8	9	10
0	\$180,000	-\$200,000	-\$220,000	-\$240,000	-\$260,000	-\$280,000	-\$300,000
1	\$180,000	-\$200,000	-\$220,000	-\$240,000	-\$260,000	-\$280,000	-\$300,000
2	\$180,000	-\$200,000	-\$220,000	-\$240,000	-\$260,000	-\$280,000	-\$300,000
3	\$70,000	\$50,000	\$30,000	\$10,000	-\$10,000	-\$30,000	-\$50,000
4	\$120,000	\$100,000	\$80,000	\$60,000	\$40,000	\$20,000	\$0
5	\$0	\$150,000	\$130,000	\$110,000	\$90,000	\$70,000	\$50,000
6	\$0	\$0	\$130,000	\$110,000	\$90,000	\$70,000	\$50,000
7	\$0	\$0	\$0	\$110,000	\$90,000	\$70,000	\$50,000
8	\$0	\$0	\$0	\$0	\$90,000	\$70,000	\$50,000
9	\$0	\$0	\$0	\$0	\$0	\$70,000	\$50,000
10	\$0	\$0	\$0	\$0	\$0	\$0	\$50,000

Shown below are the expected profits and probabilities of losing money for various batch sizes. The optimum batch size is 7, with a 0.0129 probability of losing money.

Expected Profit Number of Wafers Scheduled and Probability of Losing Money							
4	5	6	7	8	9	10	
\$20,391	\$67,627	\$88,826	\$91,073	\$81,888	\$66,718	\$48,734	
0.2617	0.1035	0.0376	0.0129	0.0273	0.0100	0.0035	

- 2.33** Shown below is the probability mass function for the number of good die castings (x) in a production batch of size Q.

# Good Parts	Number of Parts Scheduled					
	25	26	27	28	29	30
20	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
21	0.0013	0.0001	0.0000	0.0000	0.0000	0.0000
22	0.0118	0.0015	0.0002	0.0000	0.0000	0.0000
23	0.0754	0.0131	0.0018	0.0002	0.0000	0.0000
24	0.3079	0.0801	0.0144	0.0020	0.0002	0.0000
25	0.6035	0.3138	0.0847	0.0158	0.0023	0.0003
26	0.0000	0.5914	0.3194	0.0894	0.0173	0.0026
27	0.0000	0.0000	0.5796	0.3246	0.0941	0.0188
28	0.0000	0.0000	0.0000	0.5680	0.3294	0.0988
29	0.0000	0.0000	0.0000	0.0000	0.5566	0.3340
30	0.0000	0.0000	0.0000	0.0000	0.0000	0.5455

Shown below is the matrix of net profits resulting from various combinations of Q and x.

# Good Parts	Number of Parts Scheduled					
	25	26	27	28	29	30
20	-\$37,500	-\$39,000	-\$40,500	-\$42,000	-\$43,500	-\$45,000
21	-\$37,500	-\$39,000	-\$40,500	-\$42,000	-\$43,500	-\$45,000
22	-\$37,500	-\$39,000	-\$40,500	-\$42,000	-\$43,500	-\$45,000
23	-\$37,500	-\$39,000	-\$40,500	-\$42,000	-\$43,500	-\$45,000
24	-\$37,500	-\$39,000	-\$40,500	-\$42,000	-\$43,500	-\$45,000
25	\$87,500	\$86,000	\$84,500	\$83,000	\$81,500	\$80,000
26	\$0	\$86,000	\$84,500	\$83,000	\$81,500	\$80,000
27	\$0	\$0	\$84,500	\$83,000	\$81,500	\$80,000
28	\$0	\$0	\$0	\$83,000	\$81,500	\$80,000
29	\$0	\$0	\$0	\$0	\$81,500	\$80,000
30	\$0	\$0	\$0	\$0	\$0	\$80,000

Shown below are the expected profits and probabilities of losing money for various values of Q, the batch size. From the results obtained, the optimum batch size is 28. The probability of losing money, which is the probability of less than 25 die cast parts being acceptable, equals 0.0022.

Expected Profit & Probability of Losing Money						
Number of Parts Scheduled						
25	26	27	28	29	30	
\$37,933	\$74,150	\$82,456	\$82,721	\$81,468	\$79,997	
0.3965	0.0948	0.0164	0.0022	0.0003	0.0000	

- 2.34a** Shown below is the probability mass function for the number of good castings (x) produced when Q castings are produced based on a probability of 0.85 that an individual casting is good. Also shown below is a matrix of net profits resulting from the combination of Q and x . Finally, the expected profit is shown for various values of Q . Based on the results obtained, the optimum lot size is 65, with an expected profit of \$55,925.

# Good Castings	Number of Castings Scheduled											
	\$4	\$5	\$6	\$7	\$8	\$9	\$10	\$11	\$12	\$13	\$14	\$15
35	\$43,200	\$44,000	\$44,800	\$45,600	\$46,400	\$47,200	\$48,000	\$48,800	\$49,600	\$50,400	\$51,200	\$52,000
36	\$43,200	\$44,000	\$44,800	\$45,600	\$46,400	\$47,200	\$48,000	\$48,800	\$49,600	\$50,400	\$51,200	\$52,000
37	\$43,200	\$44,000	\$44,800	\$45,600	\$46,400	\$47,200	\$48,000	\$48,800	\$49,600	\$50,400	\$51,200	\$52,000
38	\$43,200	\$44,000	\$44,800	\$45,600	\$46,400	\$47,200	\$48,000	\$48,800	\$49,600	\$50,400	\$51,200	\$52,000
39	\$43,200	\$44,000	\$44,800	\$45,600	\$46,400	\$47,200	\$48,000	\$48,800	\$49,600	\$50,400	\$51,200	\$52,000
40	\$43,200	\$44,000	\$44,800	\$45,600	\$46,400	\$47,200	\$48,000	\$48,800	\$49,600	\$50,400	\$51,200	\$52,000
41	\$43,200	\$44,000	\$44,800	\$45,600	\$46,400	\$47,200	\$48,000	\$48,800	\$49,600	\$50,400	\$51,200	\$52,000
42	\$43,200	\$44,000	\$44,800	\$45,600	\$46,400	\$47,200	\$48,000	\$48,800	\$49,600	\$50,400	\$51,200	\$52,000
43	\$43,200	\$44,000	\$44,800	\$45,600	\$46,400	\$47,200	\$48,000	\$48,800	\$49,600	\$50,400	\$51,200	\$52,000
44	\$43,200	\$44,000	\$44,800	\$45,600	\$46,400	\$47,200	\$48,000	\$48,800	\$49,600	\$50,400	\$51,200	\$52,000
45	\$46,800	\$46,000	\$45,200	\$44,400	\$43,600	\$42,800	\$42,000	\$41,200	\$40,400	\$39,600	\$38,800	\$38,000
46	\$48,800	\$48,000	\$47,200	\$46,400	\$45,600	\$44,800	\$44,000	\$43,200	\$42,400	\$41,600	\$40,800	\$40,000
47	\$50,800	\$50,000	\$49,200	\$48,400	\$47,600	\$46,800	\$46,000	\$45,200	\$44,400	\$43,600	\$42,800	\$42,000
48	\$52,800	\$52,000	\$51,200	\$50,400	\$49,600	\$48,800	\$48,000	\$47,200	\$46,400	\$45,600	\$44,800	\$44,000
49	\$54,800	\$54,000	\$53,200	\$52,400	\$51,600	\$50,800	\$50,000	\$49,200	\$48,400	\$47,600	\$46,800	\$46,000
50	\$56,800	\$56,000	\$55,200	\$54,400	\$53,600	\$52,800	\$52,000	\$51,200	\$50,400	\$49,600	\$48,800	\$48,000
51	\$58,800	\$58,000	\$57,200	\$56,400	\$55,600	\$54,800	\$54,000	\$53,200	\$52,400	\$51,600	\$50,800	\$50,000
52	\$60,800	\$60,000	\$59,200	\$58,400	\$57,600	\$56,800	\$56,000	\$55,200	\$54,400	\$53,600	\$52,800	\$51,200
53	\$62,800	\$62,000	\$61,200	\$60,400	\$59,600	\$58,800	\$58,000	\$57,200	\$56,400	\$55,600	\$54,800	\$53,200
54	\$64,800	\$64,000	\$63,200	\$62,400	\$61,600	\$60,800	\$60,000	\$59,200	\$58,400	\$57,600	\$56,800	\$55,200
55	\$66,800	\$66,000	\$65,200	\$64,400	\$63,600	\$62,800	\$62,000	\$61,200	\$60,400	\$59,600	\$58,800	\$57,200
56	\$68,800	\$68,000	\$67,200	\$66,400	\$65,600	\$64,800	\$64,000	\$63,200	\$62,400	\$61,600	\$60,800	\$59,200
57	\$70,800	\$70,000	\$69,200	\$68,400	\$67,600	\$66,800	\$66,000	\$65,200	\$64,400	\$63,600	\$62,800	\$61,200
58	\$72,800	\$72,000	\$71,200	\$70,400	\$69,600	\$68,800	\$68,000	\$67,200	\$66,400	\$65,600	\$64,800	\$63,200
59	\$74,800	\$74,000	\$73,200	\$72,400	\$71,600	\$70,800	\$70,000	\$69,200	\$68,400	\$67,600	\$66,800	\$65,200
60	\$76,800	\$76,000	\$75,200	\$74,400	\$73,600	\$72,800	\$72,000	\$71,200	\$70,400	\$69,600	\$68,800	\$67,200
61	\$78,800	\$78,000	\$77,200	\$76,400	\$75,600	\$74,800	\$74,000	\$73,200	\$72,400	\$71,600	\$70,800	\$69,200
62	\$80,800	\$80,000	\$79,200	\$78,400	\$77,600	\$76,800	\$76,000	\$75,200	\$74,400	\$73,600	\$72,800	\$71,200
63	\$82,800	\$82,000	\$81,200	\$80,400	\$79,600	\$78,800	\$78,000	\$77,200	\$76,400	\$75,600	\$74,800	\$73,200
64	\$84,800	\$84,000	\$83,200	\$82,400	\$81,600	\$80,800	\$80,000	\$79,200	\$78,400	\$77,600	\$76,800	\$75,200
65	\$86,800	\$86,000	\$85,200	\$84,400	\$83,600	\$82,800	\$82,000	\$81,200	\$80,400	\$79,600	\$78,800	\$77,200
66	\$88,800	\$88,000	\$87,200	\$86,400	\$85,600	\$84,800	\$84,000	\$83,200	\$82,400	\$81,600	\$80,800	\$79,200

Expected Profit Number of Castings Scheduled												
\$4	\$5	\$6	\$7	\$8	\$9	\$10	\$11	\$12	\$13	\$14	\$15	\$16
\$24,084	\$32,877	\$39,656	\$44,687	\$48,305	\$50,873	\$52,699	\$54,001	\$54,914	\$55,514	\$55,841	\$55,975	\$55,793

- 2.34b** Shown below is the probability mass function for the number of good castings (x) produced when Q castings are produced based on a probability of 0.98 that an individual casting is good. Also shown below is a matrix of net profits resulting from the combination of Q and x . Finally, the expected profit is shown for various values of Q . Based on the results obtained, the optimum lot size is 56, with an expected profit of \$64,315.

# Good Castings	Number of Castings Scheduled												
	54	55	56	57	58	59	60	61	62	63	64	65	66
45	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
46	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
47	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
48	0.0006	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
49	0.0138	0.0007	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
50	0.034	0.0041	0.0008	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
51	0.0108	0.0195	0.0044	0.0008	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
52	0.2002	0.0734	0.0206	0.0047	0.0009	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
53	0.0000	0.2036	0.0760	0.0217	0.0050	0.0010	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
54	0.0000	0.3695	0.2069	0.0786	0.0238	0.0054	0.0011	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
55	0.0000	0.3292	0.3687	0.2101	0.0603	0.0240	0.0058	0.0012	0.0002	0.0000	0.0000	0.0000	0.0000
56	0.0000	0.0000	0.3226	0.3670	0.2133	0.0689	0.0252	0.0061	0.0013	0.0002	0.0000	0.0000	0.0000
57	0.0000	0.0000	0.0000	0.3161	0.3667	0.2164	0.0655	0.0264	0.0065	0.0014	0.0003	0.0000	0.0000
58	0.0000	0.0000	0.0000	0.0000	0.3098	0.3656	0.2194	0.0692	0.0277	0.0070	0.0015	0.0003	0.0000
59	0.0000	0.0000	0.0000	0.0000	0.0000	0.3036	0.3644	0.2223	0.0919	0.0289	0.0074	0.0016	0.0003
60	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2976	0.3630	0.2151	0.0845	0.0303	0.0079	0.0017
61	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2016	0.3416	0.2178	0.0972	0.0316	0.0083
62	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2858	0.3801	0.2304	0.0999	0.0330
63	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2801	0.3585	0.2325	
64	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2145	0.3368	0.2355
65	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2690	0.3350	
66	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.2636	

# Good Castings	Number of Castings Scheduled												
	54	55	56	57	58	59	60	61	62	63	64	65	66
45	\$16,800	\$46,000	\$45,300	\$44,400	\$43,600	\$42,800	\$42,000	\$41,300	\$40,400	\$39,600	\$38,800	\$38,000	\$37,200
46	\$48,800	\$48,000	\$47,300	\$46,400	\$45,600	\$44,800	\$44,000	\$43,300	\$42,400	\$41,600	\$40,800	\$40,000	\$39,200
47	\$50,800	\$50,000	\$49,300	\$48,400	\$47,600	\$46,800	\$46,000	\$45,300	\$44,400	\$43,600	\$42,800	\$42,000	\$41,200
48	\$52,800	\$52,000	\$51,300	\$50,400	\$49,600	\$48,800	\$48,000	\$47,300	\$46,400	\$45,600	\$44,800	\$44,000	\$43,200
49	\$54,800	\$54,000	\$53,300	\$52,400	\$51,600	\$50,800	\$50,000	\$49,300	\$48,400	\$47,600	\$46,800	\$46,000	\$45,200
50	\$56,800	\$56,000	\$55,300	\$54,400	\$53,600	\$52,800	\$52,000	\$51,300	\$50,400	\$49,600	\$48,800	\$48,000	\$47,200
51	\$58,800	\$58,000	\$57,300	\$56,400	\$55,600	\$54,800	\$54,000	\$53,300	\$52,400	\$51,600	\$50,800	\$50,000	\$49,200
52	\$60,800	\$60,000	\$59,300	\$58,400	\$57,600	\$56,800	\$56,000	\$55,300	\$54,400	\$53,600	\$52,800	\$52,000	\$51,200
53	\$0	\$62,000	\$61,300	\$60,400	\$59,600	\$58,800	\$58,000	\$57,300	\$56,400	\$55,600	\$54,800	\$54,000	\$53,200
54	\$0	\$64,000	\$63,300	\$62,400	\$61,600	\$60,800	\$60,000	\$59,300	\$58,400	\$57,600	\$56,800	\$56,000	\$55,200
55	\$0	\$66,000	\$65,300	\$64,400	\$63,600	\$62,800	\$62,000	\$61,300	\$60,400	\$59,600	\$58,800	\$58,000	\$57,200
56	\$0	\$66,000	\$64,400	\$63,600	\$62,800	\$62,000	\$61,300	\$60,400	\$59,600	\$58,800	\$58,000	\$57,200	
57	\$0	\$0	\$64,400	\$63,600	\$62,800	\$62,000	\$61,300	\$60,400	\$59,600	\$58,800	\$58,000	\$57,200	
58	\$0	\$0	\$0	\$63,600	\$62,800	\$62,000	\$61,300	\$60,400	\$59,600	\$58,800	\$58,000	\$57,200	
59	\$0	\$0	\$0	\$0	\$62,800	\$62,000	\$61,300	\$60,400	\$59,600	\$58,800	\$58,000	\$57,200	
60	\$0	\$0	\$0	\$0	\$0	\$62,000	\$61,300	\$60,400	\$59,600	\$58,800	\$58,000	\$57,200	
61	\$0	\$0	\$0	\$0	\$0	\$0	\$61,300	\$60,400	\$59,600	\$58,800	\$58,000	\$57,200	
62	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$60,400	\$59,600	\$58,800	\$58,000	\$57,200	
63	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$59,600	\$58,800	\$58,000	\$57,200	
64	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$58,800	\$58,000	\$57,200	
65	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$58,000	\$57,200	
66	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$0	\$57,200

# Good Castings	Expected Profit Number of Castings Scheduled												
	54	55	56	57	58	59	60	61	62	63	64	65	66
	\$17,527	\$63,800	\$64,315	\$64,120	\$63,528	\$62,794	\$61,991	\$61,199	\$60,400	\$59,500	\$58,800	\$58,000	\$57,200

- 2.35** In Example 2.7, $a = 2$ min, $b = 1$ min, $t = 6$ min, $n' = 2.67$, $C_o = \$15/\text{hr}$, and $C_m = \$50/\text{hr}$. Without other constraints the optimum number of machines to assign to an operator was shown to equal 2. Since $2 < n' < 3$, the economic choice was between 2 and 3 machines. Hence, two groups of 2 would be less costly, on a cost per part produced basis, than one group of 4 machines. Here, 11 machines are required to meet the production requirements. How should they be assigned? One of the alternatives being considered is to assign 2 machines to each of 4 operators and then assign 3 machines to one operator; the alternative assignment being considered is to assign 2 machines to each of 5 operators and then assign 1 machine to one operator.

To calculate the cost per unit produced for each scenario, it is useful to evaluate each alternative using a length of time equal to the least common multiple of the cycle times for each machine-operator assignment in the scenario. For example, with the {2, 2, 2, 2, 3} scenario, $T_c = 8$ min for $m = 2$ and $T_c = 9$ min for $m = 3$; therefore, a time period equal to 72 minutes will be used. During a period of 72 mins each 2-machine combination will perform 9 cycles and produce 18 parts; likewise, over the same time period, the 3-machine assignment will perform 8 cycles and produce 24 parts. Hence, over a 72 min. period, a total of $4(18) + 24$, or 96 parts will be produced. The total cost per unit produced over a 72 min. period equals $[(5 \text{ op})(\$15/\text{hr-op}) + (11 \text{ mach})(\$50/\text{hr-mach})](72 \text{ min}/60 \text{ min/hr.})(1/96 \text{ parts})$, or \$7.81/part.

For the {2, 2, 2, 2, 2, 1} scenario, $T_c = 8$ min for both $m = 1$ and $m = 2$. During an 8 min. time period a total of 11 parts are produced. The total cost per unit produced over an 8 min. period equals $[6(15) + 11(50)](8/60)(1/11)$, or \$7.76/part. Hence, the least cost alternative, in terms of cost per unit produced, is the {2, 2, 2, 2, 2, 1} scenario.

Are there other scenarios that are less costly than the two considered? No! From Example 2.7, $n^* = 2$. Hence, any scenario involving multiple assignments of single machines will be more costly than assignments of 2 machines per operator. Likewise, from the analysis performed above, any scenario involving a 3-machine assignment will be more expensive than one with a 2-machine and a 1-machine assignment. Further, any scenario having a 4-machine assignment will be more costly than one that substitutes two 2-machine assignments for the 4-machine assignment. From the analysis performed above, a 5-machine assignment will be more expensive than a {2, 2, 1} assignment. By similar analyses, there are no other scenarios that need to be considered for the assignment of 11 machines.

- 2.36** For the optimum assignment in Example 2.5 to remain unchanged, $M < 1$. Recall, in Example 2.5, $n' = 2.67$, $C_o = \$15/\text{hr}$, $C_m = \$50/\text{hr}$, and $\epsilon = C_o/C_m = 15/C_m$. Therefore, for $M < 1$, $(\epsilon + n)(n') < (\epsilon + n + 1)(n)$, or $(\epsilon + 2)(2.67) < (\epsilon + 3)(2)$, or $(15 + 2C_m)(2.67) < (15 + 3C_m)(2)$, or $(15)(2.67 - 2) < (6 - 5.33)C_m$, or $C_m > \$15/\text{hr}$. Hence, for a machine cost of \$15 or more per machine-hour, the optimum assignment will be 2 machines per operator.
- 2.37** During 7 hours of work for the operator between 8:00 a.m. and 4:00 p.m., 136 units were produced by the 3 machines. In steady state conditions, the repeating cycle is 9 minutes. Hence, in steady state conditions a total of 140 units are produced. Transient conditions due to start-up and shut-down for breaks, lunch, and beginning/ending of the shift diminish the production by only 4 units. If replacement labor is provided to keep the machines working during the entire 8-hour shift and 3 shifts operate per day, then steady state production will result in 160 units being produced per 8-hour shift. This situation is illustrated in the following multiple activity charts.

Time	Operator	Machine 1	Machine 2	Machine 3	Time	Operator	Machine 1	Machine 2	Machine 3
8:00					8:30				
1	L-1	Loaded	Idle	Idle	31	I&P-2			Idle
2	T-2				32	UL-3	Machining		Unloaded
3	L-2		Loaded		33	L-3			Loaded
4	T-3				34	I&P-3	Idle	Machining	
5	L-3				35	T-1			
6	T-1				36	UL-1	Unloaded		
7		Idle			37	L-1	Loaded		
8	UL-1	Unloaded			38	I&P-1		Idle	
9	L-1	Loaded	Idle		39	T-2			
10	I&P-1				40	UL-2		Unloaded	
11	T-2				41	L-2			Loaded
12	UL-2				42	I&P-2	Idle		Idle
13	L-2				43	T-3			Unloaded
14	I&P-2				44	UL-3			Loaded
15	T-3				45	L-3			
16	UL-3				46	I&P-3	Idle		
17	L-3				47	T-1			
18	I&P-3	Idle			48	UL-1	Unloaded		Unloaded
19	T-1				49	L-1			Loaded
20	UL-1	Unloaded			50	I&P-1		Idle	
21	L-1	Loaded			51	T-2			
22	I&P-1		Idle		52	UL-2		Unloaded	
23	T-2				53	L-2			Loaded
24	UL-2				54	I&P-2	Idle		Idle
25	L-2				55	T-3			
26	I&P-2				56	UL-3			
27	T-3				57	L-3			
28	UL-3				58	I&P-1			
29	L-3				59	T-2			
30	I&P-3	Idle			60	UL-2		Unloaded	
31	T-1				61	L-2			Loaded
32	UL-1				62	I&P-2	Idle		Idle
33	L-1				63	T-3			
34	I&P-1				64	UL-3			
35	T-2				65	L-3			
36	UL-2				66	I&P-1			
37	L-2				67	T-2			
38	I&P-2				68	UL-2		Unloaded	
39	T-3				69	L-2			Loaded
40	UL-3				70	I&P-2	Idle		Idle
41	L-3				71	T-1			
42	I&P-3	Idle			72	UL-1	Unloaded		Unloaded
43	T-1				73	L-1			Loaded
44	UL-1	Unloaded			74	I&P-1		Idle	
45	L-1	Loaded			75	T-2			
46	I&P-2				76	UL-2		Unloaded	
47	T-2				77	L-2			Loaded
48	UL-2				78	I&P-2	Idle		Idle
49	L-2				79	T-3			
50	I&P-3				80	UL-3			
51	T-1		Idle		81	L-3			
52	UL-1	Unloaded			82	I&P-1			
53	L-1	Loaded			83	T-2			
54	I&P-2				84	UL-2		Unloaded	
55	T-2				85	L-2			Loaded
56	UL-2				86	I&P-2	Idle		Idle
57	L-2				87	T-3			
58	I&P-3	Idle			88	UL-3			
59	T-1				89	L-3			
60	UL-1	Unloaded			90	I&P-1			
61	L-1	Loaded			91	T-2			
62	I&P-2				92	UL-2		Unloaded	
63	T-2				93	L-2			Loaded
64	UL-2				94	I&P-2	Idle		Idle
65	L-2				95	T-3			
66	I&P-3				96	UL-3			
67	T-1				97	L-3			
68	UL-1	Unloaded			98	I&P-1			
69	L-1	Loaded			99	T-2			
70	I&P-2				100	UL-2		Unloaded	
71	T-2				101	L-2			Loaded
72	UL-2				102	I&P-2	Idle		Idle
73	L-2				103	T-3			
74	I&P-3	Idle			104	UL-3			
75	T-1				105	L-3			
76	UL-1	Unloaded			106	I&P-1			
77	L-1	Loaded			107	T-2			
78	I&P-2				108	UL-2		Unloaded	
79	T-2				109	L-2			Loaded
80	UL-2				110	I&P-2	Idle		Idle
81	L-2				111	T-3			
82	I&P-3				112	UL-3			
83	T-1				113	L-3			
84	UL-1	Unloaded			114	I&P-1			
85	L-1	Loaded			115	T-2			
86	I&P-2				116	UL-2		Unloaded	
87	T-2				117	L-2			Loaded
88	UL-2				118	I&P-2	Idle		Idle
89	L-2				119	T-3			
90	I&P-3				120	UL-3			
91	T-1				121	L-3			
92	UL-1	Unloaded			122	I&P-1			
93	L-1	Loaded			123	T-2			
94	I&P-2				124	UL-2		Unloaded	
95	T-2				125	L-2			Loaded
96	UL-2				126	I&P-2	Idle		Idle
97	L-2				127	T-3			
98	I&P-3				128	UL-3			
99	T-1				129	L-3			
100	UL-1	Unloaded			130	I&P-1			
101	L-1	Loaded			131	T-2			
102	I&P-2				132	UL-2		Unloaded	
103	T-2				133	L-2			Loaded
104	UL-2				134	I&P-2	Idle		Idle
105	L-2				135	T-3			
106	I&P-3				136	UL-3			
107	T-1				137	L-3			
108	UL-1	Unloaded			138	I&P-1			
109	L-1	Loaded			139	T-2			
110	I&P-2				140	UL-2		Unloaded	
111	T-2				141	L-2			Loaded
112	UL-2				142	I&P-2	Idle		Idle
113	L-2				143	T-3			
114	I&P-3				144	UL-3			
115	T-1				145	L-3			
116	UL-1	Unloaded			146	I&P-1			
117	L-1	Loaded			147	T-2			
118	I&P-2				148	UL-2		Unloaded	
119	T-2				149	L-2			Loaded
120	UL-2				150	I&P-2	Idle		Idle
121	L-2				151	T-3			
122	I&P-3				152	UL-3			
123	T-1				153	L-3			
124	UL-1	Unloaded			154	I&P-1			
125	L-1	Loaded			155	T-2			
126	I&P-2				156	UL-2		Unloaded	
127	T-2				157	L-2			Loaded
128	UL-2				158	I&P-2	Idle		Idle
129	L-2				159	T-3			
130	I&P-3				160	UL-3			
131	T-1				161	L-3			
132	UL-1	Unloaded			162	I&P-1			
133	L-1	Loaded			163	T-2			
134	I&P-2				164	UL-2		Unloaded	
135	T-2				165	L-2			Loaded
136	UL-2				166	I&P-2	Idle		Idle
137	L-2				167	T-3			
138	I&P-3				168	UL-3			
139	T-1				169	L-3			
140	UL-1	Unloaded			170	I&P-1			
141	L-1	Loaded			171	T-2			
142	I&P-2				172	UL-2		Unloaded	
143	T-2				173	L-2			Loaded
144	UL-2				174	I&P-2	Idle		Idle
145	L-2				175	T-3			
146	I&P-3				176	UL-3			
147	T-1				177	L-3			
148	UL-1	Unloaded			178	I&P-1			
149	L-1	Loaded			179	T-2			
150	I&P-2				180	UL-2		Unloaded	
151	T-2				181	L-2			Loaded
152	UL-2				182	I&P-2	Idle		Idle
153	L-2				183	T-3			
154	I&P-3				184	UL-3			
155	T-1				185	L-3			
156	UL-1	Unloaded			186	I&P-1			
157	L-1	Loaded			187	T-2			
158	I&P-2				188	UL-2		Unloaded	
159	T-2				189	L-2			Loaded
160	UL-2				190	I&P-2	Idle		Idle
161	L-2				191	T-3			
162	I&P-3				192	UL-3			
163	T-1				193	L-3			
164	UL-1	Unloaded			194	I&P-1			
165	L-1	Loaded			195	T-2			
166	I&P-2				196	UL-2		Unloaded	
167	T-2				197	L-2			Loaded
168	UL-2				198	I&P-2	Idle		Idle
169	L-2				199	T-3			
170	I&P-3				200	UL-3			
171	T-1				201	L-3			
172	UL-1	Unloaded			202	I&P-1			
173	L-1	Loaded			203	T-2			
174	I&P-2				204	UL-2		Unloaded	
175	T-2				205	L-2			Loaded
176	UL-2				206	I&P-2	Idle		Idle
177	L-2				207	T-3			
178	I&P-3				208	UL-3			
179	T-1			</td					

Time	Operator	Machine 1	Machine 2	Machine 3	Time	Operator	Machine 1	Machine 2	Machine 3
9:00	I&P-3 T-1	Idle			9:30	I&P-1 T-2		Idle	
1	UL-1	Unloaded	Machining		31	UL-2		Unloaded	Machining
2	L-1	Loaded			32	L-2		Loaded	
3	I&P-1 T-2		Idle	Machining	33	I&P-2 T-3			Idle
4	UL-2		Unloaded		34	UL-3			Unloaded
5	L-2		Loaded		35	L-3			Loaded
6	I&P-2 T-3				36	I&P-3 T-1		Idle	
7	UL-3				37	UL-1		Unloaded	
8	L-3				38	L-1		Loaded	
9	I&P-3 T-1	Idle			39	I&P-1 T-2		Idle	Machining
10	UL-1	Unloaded			40	UL-2			Unloaded
11	L-1	Loaded			41	L-2			Loaded
12	I&P-1 T-2		Idle		42	I&P-2 T-3			Idle
13	UL-2		Unloaded		43	UL-3			Unloaded
14	L-2		Loaded		44	L-3			Loaded
15	I&P-2 T-3				45				
16	UL-3				46				
17	L-3				47				
18	I&P-3 T-1	Idle			48				
19	UL-1	Unloaded			49				
20	L-1	Loaded			50				
21	I&P-1 T-2		Idle		51			Idle	
22	UL-2		Unloaded		52		Break	Idle	Idle
23	L-2		Loaded		53				
24	I&P-2 T-3				54				
25	UL-3				55				
26	L-3				56				
27	I&P-3 T-1	Idle			57				
28	UL-1	Unloaded			58				
29	L-1	Loaded			59				
9:30					10:00				

Time	Operator	Machine 1	Machine 2	Machine 3	Time	Operator	Machine 1	Machine 2	Machine 3
11:00	UL-2		Unloaded	Machining	11:30	UL-3		Machining	
1	L-2		Loaded		31	L-3			Unloaded
2	I&P-2				32	I&P-3		Idle	Loaded
3	T-3				33	T-1			
4	UL-3				34	UL-1	Unloaded		
5	L-3				35	L-1	Loaded		
6	I&P-3		Idle		36	I&P-1		Idle	Machining
7	T-1				37	T-2			
8	UL-1	Unloaded			38	UL-2		Unloaded	
9	L-1	Loaded			39	L-2		Loaded	
10	I&P-1		Idle		40	I&P-2			
11	T-2				41	T-3			
12	UL-2		Unloaded		42	UL-3			
13	L-2		Loaded		43	L-3			
14	I&P-2				44	I&P-3		Idle	
15	T-3				45	T-1			
16	UL-3				46	UL-1	Unloaded		
17	L-3				47	L-1	Loaded		
18	I&P-3		Idle		48	I&P-1			
19	T-1				49	T-2			
20	UL-1	Unloaded			50	UL-2			
21	L-1	Loaded			51	L-2			
22	I&P-1		Idle		52	I&P-3		Idle	Idle
23	T-2				53	T-1			
24	UL-2		Unloaded		54	UL-1			
25	L-2		Loaded		55	L-3			
26	I&P-2				56	I&P-3			
27	T-3				57	T-1			
28	UL-3				58	UL-2			
29	L-3				59	L-1			
30	I&P-3		Idle		60	I&P-1			
31	T-1				61	T-2			
32	UL-1	Unloaded			62	UL-3			
33	L-1	Loaded			63	L-2			
34	I&P-1		Idle		64	I&P-2			
35	T-2				65	T-3			
36	UL-2		Unloaded		66	UL-3			
37	L-2		Loaded		67	L-1			
38	I&P-2				68	I&P-1			
39	T-3				69	T-2			
40	UL-3				70	UL-2			
41	L-3				71	L-1			
42	I&P-3		Idle		72	I&P-3			
43	T-1				73	T-1			
44	UL-1	Unloaded			74	UL-2			
45	L-1	Loaded			75	L-3			
46	I&P-1		Idle		76	I&P-3			
47	T-2				77	T-1			
48	UL-2		Unloaded		78	UL-1			
49	L-2		Loaded		79	L-3			
50	I&P-2				80	I&P-1			
51	T-3				81	T-2			
52	UL-3				82	UL-2			
53	L-3				83	L-1			
54	I&P-3		Idle		84	I&P-3			
55	T-1				85	T-1			
56	UL-1	Unloaded			86	UL-2			
57	L-1	Loaded			87	L-3			
58	I&P-1		Idle		88	I&P-3			
59	T-2				89	T-1			
60	UL-2		Unloaded		90	UL-1			
61	L-2		Loaded		91	L-3			
62	I&P-2				92	I&P-1			
63	T-3				93	T-2			
64	UL-3				94	UL-2			
65	L-3				95	L-1			
66	I&P-3		Idle		96	I&P-3			
67	T-1				97	T-1			
68	UL-1	Unloaded			98	UL-2			
69	L-1	Loaded			99	L-3			
70	I&P-1		Idle		100	I&P-3			
71	T-2				101	T-1			
72	UL-2		Unloaded		102	UL-1			
73	L-2		Loaded		103	L-3			
74	I&P-2				104	I&P-1			
75	T-3				105	T-2			
76	UL-3				106	UL-2			
77	L-3				107	L-1			
78	I&P-3		Idle		108	I&P-3			
79	T-1				109	T-1			
80	UL-1	Unloaded			110	UL-2			
81	L-1	Loaded			111	L-3			
82	I&P-1		Idle		112	I&P-3			
83	T-2				113	T-1			
84	UL-2		Unloaded		114	UL-1			
85	L-2		Loaded		115	L-3			
86	I&P-2				116	I&P-1			
87	T-3				117	T-2			
88	UL-3				118	UL-2			
89	L-3				119	L-1			
90	I&P-3		Idle		120	I&P-3			
91	T-1				121	T-1			
92	UL-1	Unloaded			122	UL-2			
93	L-1	Loaded			123	L-3			
94	I&P-1		Idle		124	I&P-1			
95	T-2				125	T-2			
96	UL-2		Unloaded		126	UL-3			
97	L-2		Loaded		127	L-1			
98	I&P-2				128	I&P-2			
99	T-3				129	T-3			
100	UL-3				130	UL-1			
101	L-3				131	L-2			
102	I&P-3		Idle		132	I&P-3			
103	T-1				133	T-1			
104	UL-1	Unloaded			134	UL-2			
105	L-1	Loaded			135	L-3			
106	I&P-1		Idle		136	I&P-1			
107	T-2				137	T-2			
108	UL-2		Unloaded		138	UL-3			
109	L-2		Loaded		139	L-1			
110	I&P-2				140	I&P-2			
111	T-3				141	T-3			
112	UL-3				142	UL-1			
113	L-3				143	L-2			
114	I&P-3		Idle		144	I&P-3			
115	T-1				145	T-1			
116	UL-1	Unloaded			146	UL-2			
117	L-1	Loaded			147	L-3			
118	I&P-1		Idle		148	I&P-1			
119	T-2				149	T-2			
120	UL-2		Unloaded		150	UL-3			
121	L-2		Loaded		151	L-1			
122	I&P-2				152	I&P-2			
123	T-3				153	T-3			
124	UL-3				154	UL-1			
125	L-3				155	L-2			
126	I&P-3		Idle		156	I&P-3			
127	T-1				157	T-1			
128	UL-1	Unloaded			158	UL-2			
129	L-1	Loaded			159	L-3			
130	I&P-1		Idle		160	I&P-1			
131	T-2				161	T-2			
132	UL-2		Unloaded		162	UL-3			
133	L-2		Loaded		163	L-1			
134	I&P-2				164	I&P-2			
135	T-3				165	T-3			
136	UL-3				166	UL-1			
137	L-3				167	L-2			
138	I&P-3		Idle		168	I&P-3			
139	T-1				169	T-1			
140	UL-1	Unloaded			170	UL-2			
141	L-1	Loaded			171	L-3			
142	I&P-1		Idle		172	I&P-1			
143	T-2				173	T-2			
144	UL-2		Unloaded		174	UL-3			
145	L-2		Loaded		175	L-1			
146	I&P-2				176	I&P-2			
147	T-3				177	T-3			
148	UL-3				178	UL-1			
149	L-3				179	L-2			
150	I&P-3		Idle		180	I&P-3			
151	T-1				181	T-1			
152	UL-1	Unloaded			182	UL-2			
153	L-1	Loaded			183	L-3			
154	I&P-1		Idle		184	I&P-1			
155	T-2				185	T-2			
156	UL-2		Unloaded		186	UL-3			
157	L-2		Loaded		187	L-1			
158	I&P-2				188	I&P-2			
159	T-3				189	T-3			
160	UL-3				190	UL-1			
161	L-3				191	L-2			
162	I&P-3		Idle		192	I&P-3			
163	T-1				193	T-1			
164	UL-1	Unloaded			194	UL-2			
165	L-1	Loaded			195	L-3			
166	I&P-1		Idle		196	I&P-1			
167	T-2				197	T-2			
168	UL-2		Unloaded		198	UL-3			
169	L-2		Loaded		199	L-1			
170	I&P-2				200	I&P-2			
171	T-3				201	T-3			
172	UL-3				202	UL-1			
173	L-3				203	L-2			
174	I&P-3		Idle		204	I&P-3			
175	T-1				205	T-1			
176	UL-1	Unloaded			206	UL-2			
177	L-1	Loaded			207	L-3			
178	I&P-1		Idle		208	I&P-1			
179	T-2				209	T-2			
180	UL-2		Unloaded		210	UL-3			
181	L-2		Loaded		211	L-1			
182	I&P-2				212	I&P-2			
183	T-3				213	T-3			
184	UL-3				214	UL-1			
185	L-3				215	L-2			
186	I&P-3		Idle		216	I&P-3			
187	T-1				217	T-1			
188	UL-1	Unloaded			218	UL-2			
189	L-1	Loaded			219	L-3			
190	I&P-1		Idle		220	I&P-1			
191	T-2				221	T-2			
192	UL-2		Unloaded		222	UL-3			
193	L-2		Loaded		223	L-1			
194	I&P-2				224	I&P-2			
195	T-3				225	T-3			
196	UL-3				226	UL-1			
197	L-3				227	L-2			
198	I&P-3		Idle</td						

Time	Operator	Machine 1	Machine 2	Machine 3	Time	Operator	Machine 1	Machine 2	Machine 3
12:00					12:30				
1					UL-3	Machining			Unloaded
2					L-3				Loaded
3					I&P-3	Idle			
4					T-1				
5					UL-1	Unloaded			
6					L-1	Loaded			
7	Lunch	Idle	Idle	Idle	I&P-1				
8					T-2				
9					UL-2				Unloaded
10					L-2				Loaded
11					I&P-2				Idle
12					T-3				
13					UL-3				Unloaded
14					L-3				Loaded
15	T-1				I&P-3	Idle			
16	T-2				T-1				
17	UL-2				UL-1	Unloaded			
18	L-2				L-1	Loaded			
19	I&P-2				I&P-1				
20	T-3				T-2				
21	Idle				UL-2				
22	UL-3				L-2				Loaded
23	L-3				I&P-2				Idle
24	I&P-3				T-3				
25	T-1				UL-3				Unloaded
26	UL-1				L-3				Loaded
27	Unloaded				I&P-3	Idle			
28	L-1				T-1				
29	I&P-1				UL-1	Unloaded			
30	T-2				L-1	Loaded			
31	UL-2				I&P-1				
32	L-2				T-2				
33	Unloaded				UL-2				
34	I&P-2				L-2				Loaded
35	T-3				I&P-2				Idle
36	UL-3				T-3				
37	L-3				UL-3				Unloaded
38	I&P-1				L-3				Loaded
39	T-2				I&P-3				
40	UL-2				T-1				
41	L-2				UL-1	Unloaded			
42	I&P-2				L-1	Loaded			
43	T-3				I&P-1				
44	UL-3				T-2				
45	L-3				UL-2				
46	I&P-1				L-2				Loaded
47	T-2				I&P-2				Idle
48	UL-2				T-3				
49	L-2				UL-3				Unloaded
50	I&P-2				L-3				Loaded
51	T-3				I&P-3	Idle			
52	UL-3				T-1				
53	L-3				UL-1	Unloaded			
54	I&P-1				L-1	Loaded			
55	T-2				I&P-1				
56	UL-2				T-2				
57	L-2				UL-2				
58	I&P-2				L-2				Loaded
59	T-3				I&P-2				Idle
60	UL-3				T-3				
61	L-3				UL-3				Unloaded
62	I&P-1				L-3				Loaded
63	T-2				I&P-3				
64	UL-2				T-1				
65	L-2				UL-1	Unloaded			
66	I&P-2				L-1	Loaded			
67	T-3				I&P-1				
68	UL-3				T-2				
69	L-3				UL-2				
70	I&P-3				L-2				Loaded
71	T-1				I&P-2				Idle
72	UL-3				T-3				
73	L-3				UL-3				Unloaded
74	I&P-1				L-3				Loaded
75	T-2				I&P-3				
76	UL-2				T-1				
77	L-2				UL-1	Unloaded			
78	I&P-2				L-1	Loaded			
79	T-3				I&P-1				
80	UL-3				T-2				
81	L-3				UL-2				
82	I&P-3				L-2				Loaded
83	T-1				I&P-2				Idle
84	UL-3				T-3				
85	L-3				UL-3				Unloaded
86	I&P-1				L-3				Loaded
87	T-2				I&P-3				
88	UL-2				T-1				
89	L-2				UL-1	Unloaded			
90	I&P-2				L-1	Loaded			
91	T-3				I&P-1				
92	UL-3				T-2				
93	L-3				UL-2				
94	I&P-3				L-2				Loaded
95	T-1				I&P-2				Idle
96	UL-3				T-3				
97	L-3				UL-3				Unloaded
98	I&P-1				L-3				Loaded
99	T-2				I&P-3				
100	UL-2				T-1				
101	L-2				UL-1	Unloaded			
102	I&P-2				L-1	Loaded			
103	T-3				I&P-1				
104	UL-3				T-2				
105	L-3				UL-2				
106	I&P-3				L-2				Loaded
107	T-1				I&P-2				Idle
108	UL-3				T-3				
109	L-3				UL-3				Unloaded
110	I&P-1				L-3				Loaded
111	T-2				I&P-3				
112	UL-2				T-1				
113	L-2				UL-1	Unloaded			
114	I&P-2				L-1	Loaded			
115	T-3				I&P-1				
116	UL-3				T-2				
117	L-3				UL-2				
118	I&P-3				L-2				Loaded
119	T-1				I&P-2				Idle
120	UL-3				T-3				
121	L-3				UL-3				Unloaded
122	I&P-1				L-3				Loaded
123	T-2				I&P-3				
124	UL-2				T-1				
125	L-2				UL-1	Unloaded			
126	I&P-2				L-1	Loaded			
127	T-3				I&P-1				
128	UL-3				T-2				
129	L-3				UL-2				
130	I&P-3				L-2				Loaded
131	T-1				I&P-2				Idle
132	UL-3				T-3				
133	L-3				UL-3				Unloaded
134	I&P-1				L-3				Loaded
135	T-2				I&P-3				
136	UL-2				T-1				
137	L-2				UL-1	Unloaded			
138	I&P-2				L-1	Loaded			
139	T-3				I&P-1				
140	UL-3				T-2				
141	L-3				UL-2				
142	I&P-3				L-2				Loaded
143	T-1				I&P-2				Idle
144	UL-3				T-3				
145	L-3				UL-3				Unloaded
146	I&P-1				L-3				Loaded
147	T-2				I&P-3				
148	UL-2				T-1				
149	L-2				UL-1	Unloaded			
150	I&P-2				L-1	Loaded			
151	T-3				I&P-1				
152	UL-3				T-2				
153	L-3				UL-2				
154	I&P-3				L-2				Loaded
155	T-1				I&P-2				Idle
156	UL-3				T-3				
157	L-3				UL-3				Unloaded
158	I&P-1				L-3				Loaded
159	T-2				I&P-3				
160	UL-2				T-1				
161	L-2				UL-1	Unloaded			
162	I&P-2				L-1	Loaded			
163	T-3				I&P-1				
164	UL-3				T-2				
165	L-3				UL-2				
166	I&P-3				L-2				Loaded
167	T-1				I&P-2				Idle
168	UL-3				T-3				
169	L-3				UL-3				Unloaded
170	I&P-1				L-3				Loaded
171	T-2				I&P-3				
172	UL-2				T-1				
173	L-2				UL-1	Unloaded			
174	I&P-2				L-1	Loaded			
175	T-3				I&P-1				
176	UL-3				T-2				
177	L-3				UL-2				
178	I&P-3				L-2				Loaded
179	T-1				I&P-2				Idle
180	UL-3				T-3				
181	L-3				UL-3				Unloaded
182	I&P-1				L-3				Loaded
183	T-2				I&P-3				
184	UL-2				T-1				
185	L-2				UL-1	Unloaded			
186	I&P-2				L-1	Loaded			
187	T-3				I&P-1				
188	UL-3				T-2				
189	L-3				UL-2				
190	I&P-3				L-2				Loaded
191	T-1				I&P-2				Idle
192	UL-3				T-3				
193	L-3				UL-3				Unloaded</

Time	Operator	Machine 1	Machine 2	Machine 3	Time	Operator	Machine 1	Machine 2	Machine 3
1:00	UL-1	Unloaded			1:30	UL-2			
1	L-1	Loaded	Machining		31	L-2			
2	I&P-1		Idle	Machining	32	I&P-2			
3	T-2				33	T-3			
3	UL-2		Unloaded		34	UL-3			
4	L-2		Loaded		35	L-3			
5	I&P-2			Idle	36	I&P-3			
6	T-3				37	T-1			
6	UL-3			Unloaded	38	UL-1	Unloaded		
7	L-3			Loaded	39	L-1	Loaded		
8	I&P-3		Idle		40	I&P-1			
9	T-1				41	T-2			
9	UL-1	Unloaded			42	UL-2			
10	L-1	Loaded		Machining	43	UL-3			
11	I&P-1		Idle		44	L-3			
12	T-2				45	I&P-3			
12	UL-2		Unloaded		46	T-1			
13	L-2		Loaded		47	UL-1	Unloaded		
14	I&P-2			Idle	48	L-1	Loaded		
15	T-3				49	I&P-1			
15	UL-3			Unloaded	50	T-2			
16	L-3			Loaded	51	UL-2			
17	I&P-3		Idle		52	UL-3			
18	T-1				53	L-3			
18	UL-1	Unloaded			54	I&P-3			
19	L-1	Loaded		Machining	55	T-1			
20	I&P-1		Idle		56	UL-1	Unloaded		
21	T-2				57	L-1	Loaded		
21	UL-2		Unloaded		58	I&P-1			
22	L-2		Loaded		59	T-2			
23	I&P-2			Idle	60	UL-2			
24	T-3				61	UL-3			
24	UL-3			Unloaded	62	L-3			
25	L-3			Loaded	63	I&P-3			
26	I&P-3		Idle		64	T-1			
27	T-1				65	UL-1	Unloaded		
27	UL-1	Unloaded			66	L-1	Loaded		
28	L-1	Loaded		Machining	67	I&P-1			
29	I&P-1		Idle		68	T-2			
29	T-2				69	UL-2			
29	L-2			Unloaded	70	UL-3			
1:30					71	L-3			
					72	I&P-2			
					73	T-1			
					74	Break			
					2:00				

Time	Operator	Machine 1	Machine 2	Machine 3	Time	Operator	Machine 1	Machine 2	Machine 3
2:00					2:30	UL-1	Unloaded		
1					31	L-1	Loaded	Machining	
2					32	I&P-1		Idle	Machining
3					33	T-2			
4					34	UL-2		Unloaded	
5					35	L-2		Loaded	
6					36	I&P-2	Machining	Idle	
7					37	T-3		Unloaded	
8					38	UL-3		Loaded	
9					39	L-3	Machining	Idle	Machining
10					40	I&P-3			
11					41	T-1	Idle		
12					42	UL-1	Unloaded		
13					43	L-1	Loaded		
14					44	I&P-1		Idle	
15	T-2				45	T-3			
16	T-3				46	UL-2		Unloaded	
17	UL-3				47	L-2		Loaded	
18	L-3				48	I&P-2	Machining	Idle	
19	I&P-3				49	T-1			
20	T-1				50	UL-3			
21	Idle				51	L-3	Machining		
22	UL-1	Unloaded			52	I&P-1		Idle	Machining
23	L-1	Loaded			53	T-2			
24	I&P-1				54	UL-2			
25	T-2				55	L-2		Unloaded	
26	UL-2				56	I&P-2	Machining	Idle	
27	L-2				57	T-3			
28	I&P-2				58	UL-3			
29	T-3				59	L-3			
30	UL-3				60	I&P-3			
31	L-3				61	T-1			
32	Idle				62	UL-1			
33					63	L-1			
34					64	I&P-1			
35					65	T-2			
36					66	UL-2			
37					67	L-2			
38					68	I&P-2			
39					69	T-3			
40					70	UL-3			
41					71	L-3			
42					72	I&P-3			
43					73	T-1			
44					74	UL-1			
45					75	L-1			
46					76	I&P-1			
47					77	T-2			
48					78	UL-2			
49					79	L-2			
50					80	I&P-2			
51					81	T-3			
52					82	UL-3			
53					83	L-3			
54					84	I&P-3			
55					85	T-1			
56					86	UL-1			
57					87	L-1			
58					88	I&P-1			
59					89	T-2			
60					90	UL-2			
61					91	L-2			
62					92	I&P-2			
63					93	T-3			
64					94	UL-3			
65					95	L-3			
66					96	I&P-3			
67					97	T-1			
68					98	UL-1			
69					99	L-1			
70					100	I&P-1			
71					101	T-2			
72					102	UL-2			
73					103	L-2			
74					104	I&P-2			
75					105	T-3			
76					106	UL-3			
77					107	L-3			
78					108	I&P-3			
79					109	T-1			
80					110	UL-1			
81					111	L-1			
82					112	I&P-1			
83					113	T-2			
84					114	UL-2			
85					115	L-2			
86					116	I&P-2			
87					117	T-3			
88					118	UL-3			
89					119	L-3			
90					120	I&P-3			
91					121	T-1			
92					122	UL-1			
93					123	L-1			
94					124	I&P-1			
95					125	T-2			
96					126	UL-2			
97					127	L-2			
98					128	I&P-2			
99					129	T-3			
100					130	UL-3			
101					131	L-3			
102					132	I&P-3			
103					133	T-1			
104					134	UL-1			
105					135	L-1			
106					136	I&P-1			
107					137	T-2			
108					138	UL-2			
109					139	L-2			
110					140	I&P-2			
111					141	T-3			
112					142	UL-3			
113					143	L-3			
114					144	I&P-3			
115					145	T-1			
116					146	UL-1			
117					147	L-1			
118					148	I&P-1			
119					149	T-2			
120					150	UL-2			
121					151	L-2			
122					152	I&P-2			
123					153	T-3			
124					154	UL-3			
125					155	L-3			
126					156	I&P-3			
127					157	T-1			
128					158	UL-1			
129					159	L-1			
130					160	I&P-1			
131					161	T-2			
132					162	UL-2			
133					163	L-2			
134					164	I&P-2			
135					165	T-3			
136					166	UL-3			
137					167	L-3			
138					168	I&P-3			
139					169	T-1			
140					170	UL-1			
141					171	L-1			
142					172	I&P-1			
143					173	T-2			
144					174	UL-2			
145					175	L-2			
146					176	I&P-2			
147					177	T-3			
148					178	UL-3			
149					179	L-3			
150					180	I&P-3			
151					181	T-1			
152					182	UL-1			
153					183	L-1			
154					184	I&P-1			
155					185	T-2			
156					186	UL-2			
157					187	L-2			
158					188	I&P-2			
159					189	T-3			
160					190	UL-3			
161					191	L-3			
162					192	I&P-3			
163					193	T-1			
164					194	UL-1			
165					195	L-1			
166					196	I&P-1			
167					197	T-2			
168					198	UL-2			
169					199	L-2			
170					200	I&P-2			
171					201	T-3			
172					202	UL-3			
173					203	L-3			
174					204	I&P-3			
175					205	T-1			
176					206	UL-1			
177					207	L-1			
178					208	I&P-1			
179					209	T-2			
180					210	UL-2			
181					211	L-2			
182					212	I&P-2			
183					213	T-3			
184					214	UL-3			
185					215	L-3			
186					216	I&P-3			
187					217	T-1			
188					218	UL-1			
189					219	L-1			
190					220	I&P-1			
191					221	T-2			
192					222	UL-2			
193					223	L-2			
194					224	I&P-2			
195					225	T-3			
196					226	UL-3			
197					227	L-3			
198					228	I&P-3			
199					229	T-1			
200					230	UL-1			
201					231	L-1			
202					232	I&P-1			
203					233	T-2			
204					234	UL-2			
205					235	L-2			
206					236	I&P-2			
207					237	T-3			
208					238	UL-3			
209					239	L-3			
210					240	I&P-3			
211					241	T-1			
212					242	UL-1			
213					243	L-1			
214					244	I&P-1			

Time	Operator	Machine 1	Machine 2	Machine 3	Time	Operator	Machine 1	Machine 2	Machine 3
3:00	UL-2		Unloaded	Machining	3:30	UL-3		Machining	Unloaded
1	L-2		Loaded	Machining	31	L-3			Loaded
2	I&P-2			Idle	32	I&P-3		Idle	
	T-3				33	T-1			
3	UL-3			Unloaded	34	UL-1	Unloaded		
4	L-3			Loaded	35	L-1	Loaded		
5	I&P-3		Idle		36	I&P-1		Idle	Machining
	T-1				37	T-2			
6	UL-1	Unloaded			38	UL-2		Unloaded	
7	L-1	Loaded			39	L-2		Loaded	
8	I&P-1		Idle		40	T-3			
	T-2				41	UL-3		Idle	
9	UL-2		Unloaded		42	L-3			Unloaded
10	L-2		Loaded		43	I&P-3		Loaded	
11	I&P-2			Idle	44	T-1		Idle	
	T-3				45	UL-1	Unloaded		
12	UL-3			Unloaded	46	L-1		Loaded	
13	L-3			Loaded	47	I&P-1		Idle	
14	I&P-3		Idle		48	T-2			
	T-1				49	UL-2		Unloaded	
15	UL-1	Unloaded			50	L-2		Loaded	
16	L-1	Loaded			51	I&P-2		Idle	
17	I&P-1		Idle		52	T-3			
	T-2				53	UL-3		Unloaded	
18	UL-2		Unloaded		54	L-3		Loaded	
19	L-2		Loaded		55	I&P-3			
20	I&P-2			Idle	56	T-1		Idle	
	T-3				57	UL-1	Unloaded		
21	UL-3			Unloaded	58	L-1		Loaded	
22	L-3			Loaded	59	I&P-1		Idle	
23	I&P-3		Idle		4:00	T-2			
	T-1					UL-2		Unloaded	
24	UL-1	Unloaded				L-2		Loaded	
25	L-1	Loaded				I&P-2		Idle	
26	I&P-1		Idle			T-3			
	T-2					UL-3		Unloaded	
27	UL-2		Unloaded			L-3		Loaded	
28	L-2		Loaded			I&P-3		Idle	
29	I&P-2			Idle		T-1			
	T-3					UL-1	Unloaded		
30	UL-3			Unloaded		L-1		Loaded	

- 2.38** The problem statement was overly simplified, assuming sufficient demand exists to keep 5 machines busy and sales prices of the products are such that the calculation of cost per unit produced can be performed by summing the units produced for both products. Also, it is assumed that a machine is dedicated to producing either product 1 or product 2 and cannot be assigned to produce a combination of the two products due to changeover times.

From Example 2.7, we know that two machines producing product 1 should be assigned an operator to minimize the cost per unit produced. For product 2, the optimum number of machines to assign an operator is obtained as follows for producing product 2: $n_2' = (2.5 + 8)/(2.5 + 1.5) = 2.625$; $\epsilon = 0.3$; and $\Phi = (2.3/3.3)(2.625/2) = 0.9148 < 1$; therefore, $n_2^* = 2$. Hence, it appears that 2 machines should be assigned to produce product 1 and 2 machines should be assigned to produce product 2; however, that leaves 1 machine unassigned. From the solution to Problem 2.35, we know that {2, 1} is less costly than {3} for product 1.

The alternatives to be evaluated are as follows: assign 2 machines producing product 1 to an operator and 3 machines producing product 2 to an operator; assign 2 machines producing product 1 to an operator, 2 machines producing product 2 to an operator, and 1 machine producing product 2 to an operator; assign 2 machines producing product 1 to an operator, 1 machine producing product 1 to an operator, and 2 machines producing product 2 to an operator.

Assign 2 machines producing product 1 to an operator and 3 machines producing product 2 to an operator. From Example 2.7, for product 1 the repeating cycle is 8 minutes. The repeating cycle is $3(2.5 + 1.5)$, or 12 min., for product 2. Hence, in 24 minutes, the 2 machines producing product 1 perform 3 repeating cycles and produce 6 parts, and 6 parts are produced by the 3 machines making product 2 while performing 2 repeating cycles. The total hourly cost of 2 operators and 5 machines is \$280. During a period of 24 minutes, the cost will be \$112.00; hence, the cost per unit to produce 12 parts in 8 minutes is \$9.33/part.

Assign 2 machines producing product 1 to an operator, 2 machines producing product 2 to an operator, and 1 machine producing product 2 to an operator. The repeating cycle for product 2 is 10.5 minutes. Hence, in 168 minutes there will be 21 repeating cycles for machines producing product 1 and 16 repeating cycles of machines producing product 2. The total hourly cost of 3 operators and 5 machines is \$295. During a period of 168 minutes, the cost will be \$826; hence, the cost per unit to produce 90 parts (42 of product 1 and 48 of product 2) in 168 minutes is \$9.18/part.

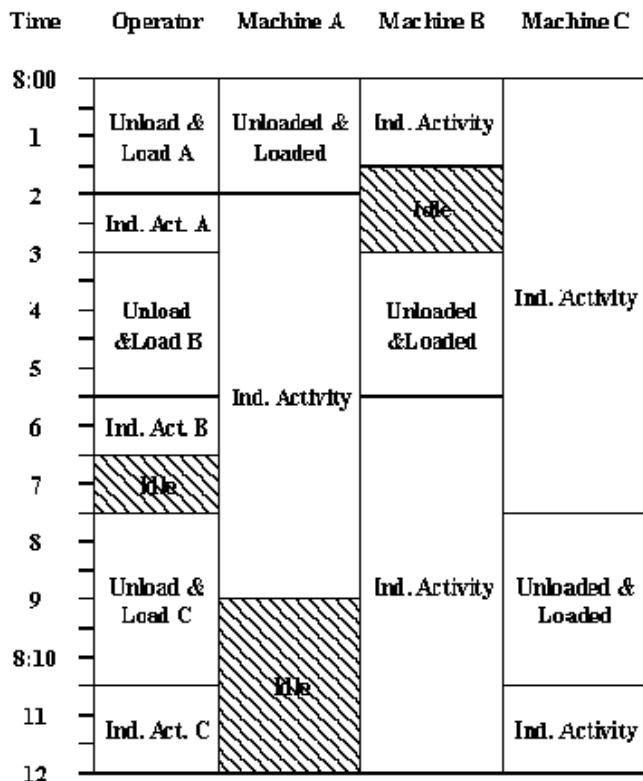
Assign 2 machines producing product 1 to an operator, 1 machine producing product 1 to an operator, and 2 machines producing product 2 to an operator. As in the previous case, the repeating cycles are 8 and 10.5 minutes. Hence, over a 168 minute time frame, there will be 21 repeating cycles of the 3 machines producing product 1 and 16 repeating cycles of the 2 machines producing product 2. The cost per unit to produce 63 units of

product 1 and 32 units of product 2 is $(\$295)(168)/(60)(95)$, or \$8.69/part. Since this is the least cost option, it would be recommended.

As noted, a simplified approach was used to arrive at a preference in the assignment of the 5 machines to the 2 products. With more information regarding sales prices, demands, changeover times, etc., a more informed decision could be made. The underlying objective in presenting the machine-assignment problem was to provide students with experience in using simple mathematical models in making decisions regarding the assignment of machines to operators.

- 2.26a** $a = 6 + 4 = 10$; $b = 6$; and $t = 30$. $n' = (10 + 30)/(10 + 6) = 2.5$. No more than 2 mixers can be assigned without idle mixer time.
- 2.26b** $C_o = \$12/\text{hr}$; $C_m = \$25/\text{hr}$; and $\epsilon = C_o/C_m = 0.48$.
Therefore, $\Phi = [(\epsilon + n)(n')]/[(\epsilon + n + 1)(n)] = [(2.5)(2.48)]/[(3.48)(2)]$, or $\Phi = 0.89 < 1$. Hence, 2 mixers should be assigned to an operator.
- 2.40** The multiple activity chart is provided on the following page. The length of the repeating cycle is given by the maximum of the following values: $(a_A + b_A + a_B + b_B + a_C + b_C)$; $(a_A + t_A)$; $(a_B + t_B)$; $(a_C + t_C)$, or max (11, 9, 10.5, 12), or 12. The repeating cycle is determined by machine C. As shown, the operator will have 1 minute of idle time during a repeating cycle, machine A will have 3 minutes of idle time, machine B will have 1.5 minutes of idle time, and machine C will have no idle time during a repeating cycle.

Multiple Activity Chart



2.41a $a = 5 \text{ min}$; $b = 1 \text{ min}$; $t = 20 \text{ min}$; $C_o = \$12/\text{hr}$, and $C_m = \$30/\text{hr}$.
 $n' = (5 + 20)/(5 + 1) = 4.167$; Therefore, 4 is the maximum number of machines that can be assigned an operator without creating machine idle time during a repeating cycle.

2.41b $\epsilon = C_o/C_m = 0.4$. Therefore,
 $\Phi = [(\epsilon + n)(n')]/[(\epsilon + n + 1)(n)] = [(4.4)(4.167)]/[(5.4)(4)]$, or $\Phi = 0.8488 < 1$. Hence, 4 mixers should be assigned to an operator.

2.41c $TC(m = 4) = [(12 + 4(30))(5 + 20)]/[(60)(4)] = \$13.75/\text{unit}$

2.41d For $n^* = 4$, either $\Phi < 1$ when $n = 4$ or $\Phi > 1$ for $n = 3$.
 $\Phi < 1$ case: $\Phi = [(0.4 + 4)(n')]/[(0.4 + 5)(4)] < 1$ or
 $\Phi = [(4.4)(a + 20)]/[(a + 1)(5.4)(4)] \Rightarrow (4.4a + 88) < (21.6a + 21.6)$.
Hence, $17.2a > 66.4$, or $a > 3.86 \text{ min}$.

$\Phi > 1$ case: $\Phi = [(3.4)(a + 20)]/[(a + 1)(4.4)(3)] < 1$. Thus, $(3.4a + 68) > (13.2a + 13.2)$. Hence, $9.8a < 54.8$, or $a < 5.59 \text{ min}$. Hence, the optimum assignment of 4 machines occurs when $3.86 \text{ min} < a < 5.59 \text{ min}$.

2.41e Consider the alternatives: {5, 5, 5}, {4, 4, 4, 3}, and {4, 5, 6}.

{5, 5, 5} case: $T_c = 30 \text{ min}$.

$$TC\{5, 5, 5\} = [3(\$12) + 15(\$30)](30/60)(1/15) = \$16.20/\text{unit}$$

{4, 4, 4, 3} case: $T_c = 25 \text{ min}$.

$$TC\{4, 4, 4, 3\} = [4(\$12) + 15(\$30)](25/60)(1/15) = \$13.83/\text{unit}$$

{4, 5, 6} case: $T_c(4) = 25 \text{ min}$, $T_c(5) = 30 \text{ min}$, $T_c(6) = 36 \text{ min}$. In 2,700 minutes, 1,332 units will be produced: 4(108), or 432, by the 4-machine assignment; 5(90), or 450, by the 5-machine assignment; and 6(75), or 450, by the 6-machine assignment.

$$TC\{4, 5, 6\} = [3(\$12) + 15(\$30)](2700/60)(1/1332) = \$16.42/\text{unit}$$

The least costly assignment of 15 machines is {4, 4, 4, 3}. We do not need to consider {3, 3, 3, 3, 3} since it has the same repeating cycle as {4, 4, 4, 3} and requires an additional operator. Likewise, there is no reason to consider an alternative involving a {3, 5} combination since we know from part a) that {4, 4} is less costly.

2.42 $a = 4 \text{ min}$; $b = 5 \text{ min} + 3 \text{ min} = 8 \text{ min}$; and $t = 40 \text{ min}$. $n' = (4 + 40)/(4 + 8)$ or $n' = 3.67$ and 3 is the maximum number of automatic palletizers on operator can be assigned without creating idle time for the palletizers.

2.43 The problem statement does not mention retrievals by the S/R; hence, no travel between the P/D station and the outbound conveyor is required. It is assumed that the travel between the P/D station of one S/R aisle and the inbound conveyor for another S/R aisle also requires 0.5 minute.

For the problem, there is no concurrent activity. As long as a load is at the P/D station, the S/R machine will retrieve it automatically. Hence, for the problem, $b = 0.5$ min to travel to the P/D station + 0.5 min to travel from the P/D station = 1.0 and $t = 4$ min to store a load and return to the end-of-the-aisle. (In Chapter 10, we define this as a single command cycle for the S/R machine.) With $b = 1$ and $t = 4$, $n' = 4$. Hence, as shown below, one lift truck operator can service 4 S/R machines; the operator and the S/R machines will be busy 100% of the time. For 5 S/R machines, 2 lift truck operators will be required.

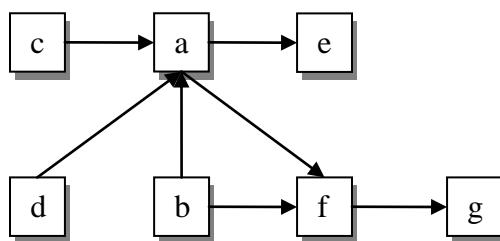
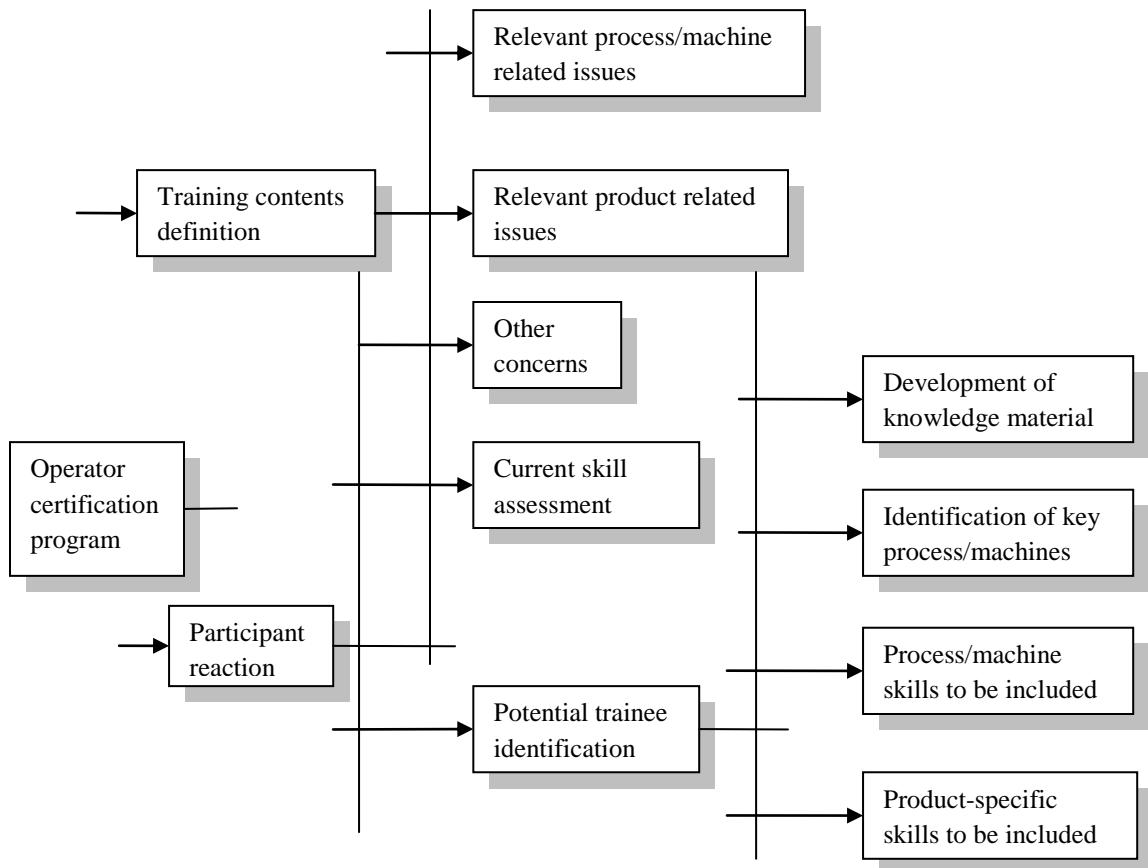
Multiple Activity Chart

Time Scale	Lift Truck Op.1	S/R A	S/R B	S/R C	S/R D
0	T-carw				
1	T-P/D B				
2	T-carw				
3	T-P/D C	Store Load			
4	T-carw				
5	T-P/D D		Store Load		
6	T-carw				
7	T-P/D A			Store Load	
8	T-carw				Store Load
	T-P/D B				
	T-carw				
	T-P/D C	Store Load			
	T-carw				
	T-P/D D		Store Load		
	T-carw				
	T-P/D A			Store Load	
					Store Load

- 2.44** $a = 0.25$ min; $b = 0$; and $t = 1.0$. Therefore, $n' = 1.25/0.25 = 5.0$. An operator can tend 5 carousels without creating idle time for the conveyors; the operator will also be 100% occupied.

SECTION 2.5

- 2.45** a. Board for part shortages
 b. Board for back-orders
 c. Feedback from material handlers when part has low physical inventory
 d. Feedback from operator handlers when part has low physical inventory

2.46**2.47**

2.48 - 2-50 The answers to these questions depend on choices made and course specifics. See Section 2.5 for details on each of the 7 M&P tools.

2.51 Follow the instructions provided in Section 2.5 for each of the 7 M&P tools.