Chapter 1

1. Design problems are problems solved at the strategic level and have a longer time frame, e.g., 3-5 years. Planning problems, on the other hand, have a shorter time frame one week to one quarter) and are addressed at the intermediate or tactical levels. Because the decisions made at the design level impact planning decision, it is desirable to solve the two problems simultaneously rather than separately.

2. Some of the criteria used for evaluating layouts include:
   - Minimize the total cost of moving material
   - Facilitate communication and supervision
   - Minimize congestion
   - Improve employee morale

   The student should be encouraged to come up with others.

3. Some constraints that analysts may encounter when developing layouts are:
   - It is too costly to move some departments or machines
   - Two departments must be located in adjacent locations
   - Two departments must not be located in adjacent locations

   The student should be encouraged to come up with others.

4. A list of the types of layout problems is provided in Section 1.3. The student should be encouraged to come up with an example for each.

5. Facility layout is a general term, because a facility can be a manufacturing facility or service facility. The term facility layout is somewhat general and could refer to facilities in an office or departments in a manufacturing plant. The term plant layout typically refers to layout of departments or cells in a manufacturing company. Machine layout refers to layout of machines within a department, cell or an entire plant. Office layout is of course, layout of offices in a service facility.

6. This is a suitable project for students early in the semester. The article by Suskind (1989) in *IE Magazine* is very helpful in conducting an operations review - a crucial step that must be undertaken before a facility design decision is made.

7. *Closed strucure* is seen in design departments of manufacturing facilities, many offices such as insurance offices, banks, etc., where personnel and their work areas are separated from others using opaque partitions. *Semiclosed strucure* is seen in banks, fast-food outlets, dry-cleaning stores and cash register areas of stores. *Open strucure* is seen in hardware stores, dining rooms, and computer labs. *Semiopen strucure* is seen in camera and eye-glass stores and in the loan processing section of a bank. The student must be encouraged to come up with examples for the four office structures.

Chapter 2

1. This is a project for the students that will help them understand: (1) the difficulty in obtaining data and (2) importance of route sheet for layout problems.

2. Product manuals for pedestal fan, garden hose bicycle, stereo racks, computer desks, and pedestal lamp are useful for this exercise.

3. This is a simple exercise once Exercise 2 is completed.

4. A course in Manufacturing Processes that is usually offered by the Mechanical Engineering department as well as several books on Manufacturing Processes in the library are good sources of information for this exercise. Students may also want to various consult technical magazines, for example, *Manufacturing Engineering*, published by the Society of Manufacturing Engineers (SME).

5. The equipment selection and layout problems are related in the sense that the latter cannot be solved unless the former has been addressed. Typically, these problems are addressed in sequence - equipment selection first and layout next. More discussion is provided in Section 2.4.

6. Using the formula $NM = \left[\frac{tP}{\tau\eta}\right]$, where [x] is the smallest integer greater than or equal to x,

   we get NM = 1000*(57/3600)/(8*0.99)=1.99 or 2 injection molding machines.

7. If the scrap rate is 10%, we have to use the $N_{il} = N_{ol} /(1-S_l)$ formula to determine the number of units to be produced per day as 1000/(1-0.1)=1112 units. Using the value of 1112 as the daily production rate and formula (2.1), we get NM = 2.22 or 3 injection molding machines. Clearly, the answer is different and we must buy one more injection molding machine if the scrap rate is 10%.

8. The formula $N_{il} = N_{ol} /(1-S_l)$ is modified as $N_{il} = N_{ol} /[1-S_l(1-RW_l)$ where RW_l is the rework rate. Because some of the "scrap" can be reworked, the daily production rate should be lower than before. In fact, the number of units to be produced per day is 1000/(1-0.1*(1-0.3))=1076 units. Using the value of 1076 as the daily production rate and formula (2.1), we get NM = 2.15 or 3 injection molding machines. Clearly, the answer is different from the one in Exercise 6, but the same as that in Exercise 7. For this problem, unless the rework rate is very high, i.e., close to 100%, we will need 3 injection molding machines.

9. Assuming an 8-hour production day, and using formulas (2.1) and (2.2), we get the required number of machines as shown in the table.

Machine	Hourly Prod Rate	Required Output	Scrap Rate	Required Input	No. of Machines
Lathe	6	103	0.05	109	3
Drill	10	100	0.08	109	2
Knurl	15	100	0.12	114	2
Buff	18	100	0.1	112	1

10. Using formula 2.1, we find that the manufacturer must purchase 10000*(10/3600)/(0.95*16)=1.82 or 2 punch presses.

11. With a scrap rate of 10% and using formula (2.2), we find that the manufacturer needs 111120*(10/3600)/(0.95*16)=2.03 or 3 punch presses.

12. The formula $N_{il} = N_{ol} /(1\text{-}S_l)$ is modified as $N_{il} = N_{ol} /[1\text{-}S_l (1\text{-}RW_l)$ where RW_l is the rework rate. Because some of the "scrap" can be reworked, the daily production rate should be lower than before. In fact, the number of units to be produced per day is 10000/(1-0.1*(1-0.3))=10753 units. Using the value of 10753 as the daily production rate and formula (2.1), we get NM = 1.97 or 2 punch presses. Clearly, the answer is different from the one in Exercise 11, but the same as that in Exercise 10.

13d. Based on the information provided, we do a backward calculation (from process D) of the input units required at each process using formula (2.2). Note that the output units at a process is equal to the input units at the succeeding process. As required, output units at D must be 1,000,000.

	A	**B**	**C**	**D**
Setup	1800	2700	600	1000
Processing time	25	4	2	4
Scrap rate	0.1	0.05	0.01	0.01
Output	1074004.26	1020304	1010101	1000000
Input	1193338.07	1074004	1020304	1010101

13e. Total cost is $150,000 as shown below.

	A	**B**	**C**	**D**
Required daily production rate	4773.35	4296.02	4081.22	4040.40

Available time per day for 1st machine	12600	11700	13800	13400
Available time per day for additional machines	27000	26100	28200	27800
Available capacity per day on 1st machine	504	2925	6900	3350
Available capacity per day on additional machines	1080	6525	14100	6950
Number of additional machines required	3	0	0	0
Cost per machine	50000	200000	100000	100000
Total cost	150000	0	0	0

13f. If half of second shift is used, additional pieces of each type of equipment must still be purchased as shown below. Note that the new machines are available for 12 hours, whereas the existing ones for 8 hours. It turns out that we can make do with fewer machines of equipment type A. The decrease in equipment purchase costs is more than offset by the overtime costs, so it is better to purchase the additional machines.

Total cost is $360,000 as shown below.

	A	**B**	**C**	**D**
Required daily production rate	4773.35	4296.02	4081.22	4040.40
Available time per day for 1st machine	27000	26100	28200	27800
Available time per day for additional machines	41400	40500	42600	42200
Available capacity per day on 1st machine	1080	6525	14100	6950
Available capacity per day on additional machines	1656	10125	21300	10550
Number of additional machines required	1	0	0	0
Cost per machine	50000	200000	100000	100000
Total cost	50000	0	0	0

14d. Based on the information provided, we do a backward calculation (from process D) of the input units required at each process using formula (2.2). Note that the output units at a process is equal to the input units at the succeeding process. As required, output units at D must be 1,000,000.

	A	**B**	**C**	**D**
Setup	1800	2700	600	1000
Processing time	25	4	2	4
Scrap rate	0.1	0.05	0.01	0.01
Output	1074004.26	1020304	1010101	1000000
Input	1193338.07	1074004	1020304	1010101

14e. Total cost is $150,000 as shown below.

	A	**B**	**C**	**D**
Required daily production rate	4773.35	4296.02	4081.22	4040.40
Available time per day for 1st machine	18360	17460	19560	19160
Available time per day for additional machines	27000	26100	28200	27800
Available capacity per day on 1st machine	734.4	4365	9780	4790
Available capacity per day on additional machines	1080	6525	14100	6950
Number of additional machines required	3	0	0	0
Cost per machine	50000	200000	100000	100000
Total cost	150000	0	0	0

14f. If half of second shift is used, additional pieces of each type of equipment must still be purchased as shown below. Note that the new machines are available for 12 hours, whereas the existing ones for 8 hours. It turns out that we can make do with fewer machines of equipment type A. As in Exercise 13, the decrease in equipment purchase costs is more than offset by the overtime costs, so it is better to purchase the additional machines.

Total cost is $360,000 as shown below.

	A	**B**	**C**	**D**
Required daily production rate	4773.35	4296.02	4081.22	4040.40
Available time per day for 1st machine	32760	31860	33960	33560
Available time per day for additional machines	41400	40500	42600	42200
Available capacity per day on 1st machine	1310.4	7965	16980	8390
Available capacity per day on additional machines	1656	10125	21300	10550
Number of additional machines required	1	0	0	0
Cost per machine	50000	200000	100000	100000
Total cost	50000	0	0	0

15. The LINDO model is setup and solved as shown below. Note from the RHS of constraints (2.4)-(2.8) that we have taken into consideration the fact that the products must be transported for the intermediate operations. For example, part P1 needs to be transported from a machine doing the first operation to another doing the second operation and then to a third machine for the last operation. We assume that the loading and unloading (for all part types) is done by another device.

```
MIN     140000 NM1 + 192000 NM2 + 85000 NM3 + 260000 NM4 + 100000 NMH1
     + 120000 NMH2 + 20 X11 + 15 X12 + 40 X13 + 21 X21 + 12 X31 + 35 X33
     + 12 X41 + 25 X43 + 10 X53 + 8 X54 + 8 X62 + 5 X64 + 12 X72 + 15 X82
     + 8 X84 + 50 Y11 + 55 Y12 + 65 Y21 + 70 Y22 + 65 Y31 + 60 Y42
     + 50 Y51 + 50 Y52
SUBJECT TO
       2)   X11 + X12 + X13 >=   20
       3)   X21 >=   50
       4)   X31 + X33 >=   35
       5)   X41 + X43 >=   45
       6)   X53 + X54 >=   30
       7)   X62 + X64 >=   25
       8)   X72 >=   20
       9)   X82 + X84 >=   30
      10) - 5000 NM1 + 18 X11 + 15 X21 + 4 X31 + 8 X41 <=   0
```

```
       11) - 5000 NM2 + 17 X12 + 8 X62 + 20 X72 + 15 X82 <=   0
       12) - 5000 NM3 + 12 X13 + 19 X33 + 12 X43 + 10 X53 <=   0
       13) - 5000 NM4 + 5 X54 + 12 X64 + 12 X84 <=   0
       14)   Y11 + Y12 >=   40
       15)   Y21 + Y22 >=   45
       16)   Y31 >=   60
       17)   Y42 >=   20
       18)   Y51 + Y52 >=   30
       19) - 5000 NMH1 + 50 Y11 + 70 Y21 + 35 Y31 + 25 Y51 <=   0
       20) - 5000 NMH2 + 55 Y12 + 70 Y22 + 60 Y42 + 50 Y52 <=   0
       21)   140000 NM1 + 192000 NM2 + 85000 NM3 + 260000 NM4 + 100000 NMH1
      + 100000 NMH2 <=   850000
 END
 GIN      6

LP OPTIMUM FOUND AT STEP    136
OBJECTIVE VALUE =   288510.000

DELETE     NMH1 AT LEVEL     1
ENUMERATION COMPLETE. BRANCHES=    24 PIVOTS=     219

LAST INTEGER SOLUTION IS THE BEST FOUND
RE-INSTALLING BEST SOLUTION...

       OBJECTIVE FUNCTION VALUE

       1)      652185.7

 VARIABLE        VALUE          REDUCED COST
      NM1         1.000000     140000.000000
      NM2         1.000000     192000.000000
      NM3         1.000000      85000.000000
     NMH1         1.000000      99642.860000
     NMH2         1.000000     120000.000000
      X12        20.000000           .000000
      X21        50.000000           .000000
      X31        35.000000           .000000
      X41        45.000000           .000000
      X53        30.000000           .000000
      X62        25.000000           .000000
      X72        20.000000           .000000
      X82        30.000000           .000000
      Y11        40.000000           .000000
      Y21        12.857140           .000000
      Y22        32.142860           .000000
      Y31        60.000000           .000000
      Y42        20.000000           .000000
      Y52        30.000000           .000000
```

16. The LINDO solution output indicates there is a slack of 233000 units in the 21st (budget) constraint. It is therefore not a binding constraint and will not have any impact on the solution even if we had ignored it. Because this is the only constraint in which information pertaining to machines *and* material handling carriers appear, this tells us that we may decompose the problem in Exercise 15 into two parts - one pertaining to machines and another pertaining to material handling carriers, solve each separately and

then combine the two solutions to get a solution to the problem in Exercise 15. This is verified by the solution to Exercises 17 and 18.

17. The model ignoring data concerning machines (in Exercise 15) and its solution are shown below.

```
 MIN     100000 NMH1 + 120000 NMH2 + 50 Y11 + 55 Y12 + 65 Y21 + 70 Y22
      + 65 Y31 + 60 Y42 + 50 Y51 + 50 Y52
 SUBJECT TO
        2)   Y11 + Y12 >=   40
        3)   Y21 + Y22 >=   45
        4)   Y31 >=   60
        5)   Y42 >=   20
        6)   Y51 + Y52 >=   30
        7) - 5000 NMH1 + 50 Y11 + 70 Y21 + 35 Y31 + 25 Y51 <=   0
        8) - 5000 NMH2 + 55 Y12 + 70 Y22 + 60 Y42 + 50 Y52 <=   0
        9)   100000 NMH1 + 100000 NMH2 + 140000 NM1 + 192000 NM2 + 85000 NM3
      + 260000 NM4 <=   850000
 END
 GIN      2

LP OPTIMUM FOUND AT STEP     28
OBJECTIVE VALUE =   200325.000
ENUMERATION COMPLETE. BRANCHES=     6 PIVOTS=      38

LAST INTEGER SOLUTION IS THE BEST FOUND
RE-INSTALLING BEST SOLUTION...

       OBJECTIVE FUNCTION VALUE

       1)      231685.7

 VARIABLE        VALUE          REDUCED COST
     NMH1         1.000000       99642.860000
     NMH2         1.000000      120000.000000
      Y11        40.000000            .000000
      Y21        12.857140            .000000
      Y22        32.142860            .000000
      Y31        60.000000            .000000
      Y42        20.000000            .000000
      Y52        30.000000            .000000
```

18. The model ignoring data concerning material-handling carriers (in Exercise 15) and its solution are shown below.

```
 MIN     140000 NM1 + 192000 NM2 + 85000 NM3 + 260000 NM4 + 20 X11
      + 15 X12 + 40 X13 + 21 X21 + 12 X31 + 35 X33 + 12 X41 + 25 X43
      + 10 X53 + 8 X54 + 8 X62 + 5 X64 + 12 X72 + 15 X82 + 8 X84
 SUBJECT TO
        2)   X11 + X12 + X13 >=   20
        3)   X21 >=   50
        4)   X31 + X33 >=   35
        5)   X41 + X43 >=   45
        6)   X53 + X54 >=   30
        7)   X62 + X64 >=   25
```

```
        8)    X72 >=   20
        9)    X82 + X84 >=   30
       10) - 5000 NM1 + 18 X11 + 15 X21 + 4 X31 + 8 X41 <=   0
       11) - 5000 NM2 + 17 X12 + 8 X62 + 20 X72 + 15 X82 <=   0
       12) - 5000 NM3 + 12 X13 + 19 X33 + 12 X43 + 10 X53 <=   0
       13) - 5000 NM4 + 5 X54 + 12 X64 + 12 X84 <=   0
       14)   140000 NM1 + 192000 NM2 + 85000 NM3 +
260000 NM4 <=   850000
  END
  GIN      4

 LP OPTIMUM FOUND AT STEP     15
 OBJECTIVE VALUE =   88185.0000
 ENUMERATION COMPLETE. BRANCHES=     5 PIVOTS=      50

 LAST INTEGER SOLUTION IS THE BEST FOUND
 RE-INSTALLING BEST SOLUTION...

       OBJECTIVE FUNCTION VALUE

       1)      420500.0

  VARIABLE        VALUE          REDUCED COST
       NM1         1.000000     140000.000000
       NM2         1.000000     192000.000000
       NM3         1.000000      85000.000000
       X12        20.000000           .000000
       X21        50.000000           .000000
       X31        35.000000           .000000
       X41        45.000000           .000000
       X53        30.000000           .000000
       X62        25.000000           .000000
       X72        20.000000           .000000
       X82        30.000000           .000000
```

λ, μ

19. The number of machines must be such that λ / μ < 1. Because are 125 and 63.16 per hour, the company must purchase two machines so that λ / μ < 1. Using the appropriate formulae from Table A.1 in the appendix, it is easy to verify the following results.

20. The number of machines must be such that λ / μ < 1. Because are 125 and 63.16 per hour, the company must purchase two machines so that λ / μ < 1. Using the appropriate formulae from Table A.1 and equations A.24 and A.25 in the appendix, it is easy to verify the following results. Note that the average waiting time and the number of units on or waiting for the machine has decreased significantly because the variability in the service times in Exercise 20 are much smaller than that in Exercise 19.

21. As can be seen from the summary of the results below, when the number of forms doubled and the operator was expected to have a backlog of 48 forms, the fact that the operator had only 25 forms means that contrary to what the supervisor believed, the employee was working very hard to clear the backlog and should have been commended for superior performance instead of being fired!

Arrival rate	125
Service rate	63.15789474
No. of servers	2
	Expo
Server utilization	98.70%
Ave waiting time	0.636 hours
Ave . Number of units waiting	79.497

Arrival rate	125
Service rate	63.15789474
No. of servers	2
	Gen
Server utilization	98.70%
Ave waiting time	0.328 hours
Ave . Number of units waiting	41.061

	Last year	This year
Arrival rate	2.5	4.9
Service rate	5	5
No. of servers	1	1
Server utilization	50.00%	98.00%
Ave waiting time	0.4 weeks	10 weeks
Ave . Number of units waiting	1 form	49 forms

22a. The total space required is shown in the table below.

	Length	Width	New Length	New Width	No. of M/Cs	**Space Reqd**
Hobbing	10	5	30	25	1	**25**
Punch Press	10	10	30	30	1	**30**
Extruding	20	10	36	26	2	**52**
Inj Molding	10	10	26	26	3	**78**
Surf Fin	5	5	21	21	4	**84**
Deburr	10	10	26	26	2	**52**
Total						**321**

22b. The total space required is shown in the table below.

Machine	Length	Width	Area	Aux. Area	Oper Space	Matl Space	Sub-Total	Allowance	Tot Space / Machine	No. of Machines	**Total Space /Mach Type**
Hobbing	10	5	50	5	4.4	10	69.4	55.52	125	1	**125**
Punch Press	10	10	100	10	8.8	20	138.8	111.04	250	1	**250**
Extruding	20	10	200	20	17.6	40	277.6	222.08	500	2	**1000**
Inj Molding	10	10	100	10	8.8	20	138.8	111.04	250	3	**750**
Surf Fin	5	5	25	2.5	2.2	5	34.7	27.76	62	4	**248**
Deburr	10	10	100	10	8.8	20	138.8	111.04	250	2	**500**
Total											**2873**

Chapter 3

1. A list is provided in Section 3.2. After reading Chapter 3, students should be able to come up with a few paragraphs describing how each data can be obtained.

2. See Section 3.2.1.

3. See Section 3.2.1. Most Production and Operations Management text-books discuss several advantages and disadvantages of each type of layout.

4. This is a mini-project for students.

5. After completing Exercise 4, students should have no problem in doing Exercise 5.

6. This is another mini-project for students.

7. This is another mini-project for students.

8a. A possible relationship chart is shown below. Departments 1-4 are the real estate agents' offices, and the other department numbers correspond to the remaining list of "offices" in Exercise 8. (Students should be encouraged to visit a real estate agent's office, find out what other "offices" need to be considered, interview personnel there and then construct a relationship chart.)

	1	2	3	4	5	6	7	8	9	10
1	-	I	I	I	A	E	U	I	E	I
2	I	-	I	I	E	U	E	I	E	I
3	I	I	-	I	E	U	E	I	E	I
4	I	I	I	-	E	U	E	I	E	I
5	A	E	E	E	-	E	E	A	E	I
6	E	U	U	U	E	-	E	U	X	U
7	U	E	E	E	E	E	-	U	X	U
8	I	I	I	I	A	U	U	-	O	U
9	E	E	E	E	E	X	X	O	-	U
10	I	I	I	I	I	U	U	U	U	-