b. Are there differences in the mean typing efficiencies for the three types of music? Use $\alpha = .05$.
c. Does the additive model for a randomized complete block design appear to be appropriate? (*Hint:* Plot the data as was done in Figure 15.1.)
d. Compute the relative efficiency of the randomized block design compared to a completely randomized design. Interpret this value. Were the blocks effective in reducing the variability in experimental units? Explain.

Psy. **15.7** Refer to Exercise 15.6. Do the model conditions appear to be satisfied?

15.3 Latin Square Design

Ag. **15.8** An experiment compared two different fertilizer placements (broadcast, band) and two different rates of fertilizer flow on watermelon yields. Recent research has shown that broadcast application (scattering over the outer area) of fertilizer is superior to bands of fertilizer applied near the seed for watermelon yields. For this experiment, the investigators wished to compare two nitrogen–phosphorus–potassium fertilizers applied (broadcast and band) at a rate of 160–70–135 pounds per acre and including two brands of micronutrients (A and B). These four combinations were to be studied in a Latin square field plot.

The treatments were randomly assigned according to a Latin square design conducted over a large farm plot, which was divided into rows and columns. A watermelon plant dry weight was obtained for each row–column combination 30 days after the emergence of the plants. The data are shown next.

	Column							
Row	1		2		3		4	
1	1	1.75	3	1.43	4	1.28	2	1.66
2	2	1.70	1	1.78	3	1.40	4	1.31
3	4	1.35	2	1.73	1	1.69	3	1.41
4	3	1.45	4	1.36	2	1.65	1	1.73

Treatment 1–broadcast, A Treatment 3–band, A
Treatment 2–broadcast, B Treatment 4–band, B

a. Write an appropriate statistical model for this experiment.
b. Use the data to run an analysis of variance. Give the p-value for each test, and draw conclusions.

Ag. **15.9** Refer to Exercise 15.8.
a. Describe how the four fertilizer placement–rate combinations are randomly assigned to the rows and columns in the farm plot.
b. Compute the relative efficiency of the Latin square design compared to a completely randomized design. Were the row- and column-blocking variables effective in reducing the variability in the responses from the experimental units? Justify your answer.
c. If future studies were to be conducted, would you recommend using both rows and columns as blocking variables? Explain your answer.

Engin. **15.10** A petroleum company was interested in comparing the miles per gallon achieved by four different gasoline blends (A, B, C, and D). Because there can be considerable variability due to differences in driving characteristics and car models, these two extraneous sources of variability were included as blocking variables in the study. The researcher selected four different brands of cars and four different drivers. The drivers and brands of cars were assigned to blends in the manner displayed in the following table. The mileage (in mpg) obtained over each test run was recorded as follows.

	Car Model			
Driver	1	2	3	4
1	A(15.5)	B(33.8)	C(13.7)	D(29.2)
2	B(16.3)	C(26.4)	D(19.1)	A(22.5)
3	C(10.5)	D(31.5)	A(17.5)	B(30.1)
4	D(14.0)	A(34.5)	B(19.7)	C(21.6)

a. Write a model for this experimental setting.
b. Estimate the parameters in the model.
c. Conduct an analysis of variance. Use $\alpha = .05$.
d. What conclusions can you draw concerning the best gasoline blend?
e. Compute the relative efficiency of the Latin square design compared to a completely randomized design. Interpret this value. Were the blocking variables effective in reducing the variability in experimental units? Explain.
f. If future studies were to be conducted, would you recommend using both car model and driver as blocking variables? Explain.

Engin. **15.11** Refer to Exercise 15.10.
a. Do the model conditions appear to be satisfied for this set of data? Explain.
b. If the model conditions appear to be violated, suggest an alternative method of analysis.

15.4 Factorial Treatment Structure in a Randomized Complete Block Design

Med. **15.12** A psychologist is designing a study to evaluate three new treatments for a behaviorial problem in children. The psychologist will include a second factor, which will classify the subjects according to four levels of socioeconomic status. There are 30 children available for each level of socioeconomic level, which will provide 10 replications of each of the treatments by socioeconomic combinations. At the end of the treatment period, the children will be assessed and assigned a score reflecting the degree of improvement in their behavior. There are five trained evaluators who will assign the scores to the children. The psychologist knows from past studies that some evaluators tend to assign uniformly higher scores than other evaluators, and, hence, he wants to be able to control for the evaluator effect in the analysis of the treatment–socioeconomic status effect.
a. Display how you would randomly assign the children to the 12 treatment–socioeconomic status combinations.
b. Provide an analysis of variance table for this experiment (source of variation and degrees of freedom).

Ag. **15.13** An entomologist employed by a chemical company is planning a study to evaluate two new chemicals that are potential agents for eliminating fire ants. The chemicals will be evaluated at three different dose levels under four different environmental conditions. One hundred ants will be exposed to each of the combinations of a chemical, dose level, and environmental condition, and the number of surviving ants after 3 hours of exposure will be recorded. It is well documented in the literature that there is large variability in the degree of tolerance of fire ants to various chemicals previously used as insecticides. Thus, the company's statistician recommended that five colonies of ants be used in the study. There are thousands of fire ants per colony.
a. Display how you would randomly assign the groups of 100 ants to the various combinations of chemical–dose–environmental condition.
b. Provide an analysis of variance table for this experiment (source of variation and degrees of freedom).

Gov. **15.14** The transportation research division of a northern state is examining the amount of road damage associated with various methods used to clear snow and ice from the roadways. The

division engineers have selected two levels of each of the following substances that are applied to the roadways: sodium chloride, calcium chloride, and sand. The response variable measured on each of the treated roads is the number of new cracks per mile of roadway. Because traffic volume is highly variable and could impact the response variable, the engineers decide to use a randomized block design with the traffic volume during the previous winter as the blocking factor. Each of the six treatments is randomly assigned to five roadways. The data are given here.

	Sodium Chloride		Calcium Chloride		Sand	
Roadway	**Low**	**High**	**Low**	**High**	**Low**	**High**
1	37	49	43	47	27	33
2	39	50	42	48	27	31
3	48	52	47	50	36	37
4	44	57	45	54	34	37
5	54	68	56	63	45	44

a. Write a statistical model for this experiment.
b. Use a profile plot to display the interaction between treatment and level.
c. Perform appropriate F tests, and draw conclusions from these tests concerning the effect of treatment and level on the mean number of cracks.
d. Use a normal probability plot and a plot of the residuals to determine if there are violations in the appropriate conditions for validly drawing conclusions from the F tests.

Gov. **15.15** Refer to Exercise 15.14.
a. Describe how the treatments would be randomly assigned to the roadways.
b. Compute the relative efficiency of the randomized block design compared to a completely randomized design. Was the blocking of the roadways based on traffic volume effective in reducing the variability in the counts of number of cracks? Explain.
c. If this study was repeated during the next winter, would you recommend that traffic volume be used to block the roadways, or would it be more efficient to design the study as a completely randomized design?

Ag. **15.16** An agricultural experiment station is investigating the appropriate planting density for three commercial varieties of tomatoes: celebrity, sunbeam, and trust. The researcher decides to examine the effects of four planting densities: 5, 20, 35, and 50 thousand plants per hectare. The experiment station has three large fields that would be appropriate for the study. At each of the fields, 12 plots are prepared, and the 12 treatments are randomly assigned to the plots. A separate randomization is done at each of the three fields. The yield, in tons, from the 36 one hectare plots are given here.

	Variety											
	Celebrity				Sunbeam				Trust			
	Density				Density				Density			
Field	**5k**	**20k**	**35k**	**50k**	**5k**	**20k**	**35k**	**50k**	**5k**	**20k**	**35k**	**50k**
1	32.5	39.9	42.5	38.2	32.2	43.2	47.6	43.5	49.9	59.0	66.3	58.3
2	33.4	47.2	44.5	43.5	33.4	51.3	52.2	44.1	60.8	66.1	70.7	60.6
3	41.1	48.7	53.5	48.4	41.8	51.2	55.9	55.9	60.8	67.6	73.2	67.8

a. Identify the design, and write a statistical model for this experiment.
b. Use a profile plot to display the level of interaction between treatment and level.
c. Perform appropriate F tests, and draw conclusions from these tests concerning the effect of variety and planting density on the mean yield of the tomato plants.
d. Use a normal probability plot and a plot of the residuals to determine if there are violations in the appropriate conditions for validly drawing conclusions from the F tests.