

A regression analysis can be conducted using the significant factors only. The regression equation in Example 7.3 shows that Yield increases as Time increases and Catalyst decreases. Based on the combined ANOVA and regression analysis, the high level of Time and low level of Catalyst should be used with the most economical level of Reactant in order to increase yield. Based on the regression equation, further experimentation with lower levels of Catalyst and longer times might result in even higher yields.

EXAMPLE 7.3: Regression Analysis: Yield versus Time, Catalyst

The regression equation is

$$\text{Yield} = 73.8 + 26.4 \text{ Time} - 16.1 \text{ Catalyst}$$

Predictor	Coef	SE Coef	T	P
Constant	73.82	16.95	4.35	0.001
Time	26.358	7.796	3.38	0.005
Catalyst	-16.135	4.677	-3.45	0.004

S = 23.3869 R-Sq = 64.2% R-Sq(adj) = 58.7%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	2	12761.3	6380.7	11.67	0.001
Residual Error	13	7110.3	546.9		
Total	15	19871.6			

Analysis using Minitab™

TAGUCHI METHODS OF EXPERIMENTAL DESIGN

In the early 1980s Professor Genichi Taguchi introduced his approach to using experimental design for:

1. designing products or processes so that they are robust to environmental conditions;
2. designing/developing products so that they are robust to component variation; and
3. minimizing variation around a target.

Taguchi refers to these three activities as quality engineering. They flow in order from system design to tolerance design. System design occurs in the initial or idea phase of product or process development. Parameter design is the middle component

of the three, where the system is “fine tuned” to ensure that it consistently functions as intended. Tolerance design determines the acceptable variations around the nominal settings determined in parameter design.

Taguchi took assumptions from engineering knowledge and used them to reduce the size of experiments, thereby speeding up the experimental process. One of the areas he looked at involved random noise and its effect on variability. Taguchi focused on minimizing the effect of the causes of variation. By inserting a second orthogonal array into the experiment, Taguchi added the capability of determining those combinations of controllable factors that minimize the effect of the sources of experimentation variability. He defined this ability as *robustness*. In other words, the product or process performs consistently on target and is relatively insensitive to factors that are difficult to control.

The purpose of experimentation using Taguchi methods is to identify the key factors that have the greatest contribution to variation and to ascertain those settings or values that result in the least variability. Dr. Taguchi adapted orthogonal arrays for designing and analyzing experimental data. Orthogonal arrays are used to control experimental error. Taguchi methods use orthogonal arrays to measure the effect of a factor on the average result, and also to determine the variation from the mean. The primary advantage of orthogonal arrays is the relationship among the factors under investigation. For each level of any one factor, all levels of the other factors occur an equal number of times. This constitutes a balanced experiment and permits the effect of one factor under study to be separable from the effects of other factors. The result is that the findings of the experiment are reproducible. This compares with full-factor analysis in which the effect of each and every variable on each and every other variable must be determined (adding significantly to the time and cost of the experiment), and single-factor analysis in which factors not of interest are eliminated (jeopardizing the reproducibility of the study). Figure 7.6 shows an example of an orthogonal array.

To enhance the flexibility of the arrays, Dr. Taguchi used linear graphs to represent the arrays. By using these graphs and the triangular tables provided by Taguchi, the experimenter can effectively study the interactions between experimental factors as well as the effects of the individual factors (main effects) themselves. Linear graphs make this possible by providing a logical scheme for assigning interactions to the

This design may be used for three factors at two levels.

Run	A	B	C
1	-1	-1	-1
2	-1	+1	+1
3	+1	-1	+1
4	+1	+1	-1

Note that this design consists of runs 1, 7, 6, and 4 of the 2^3 full-factorial design.

Figure 7.6. $L_4 (2^3)$ Orthogonal Array

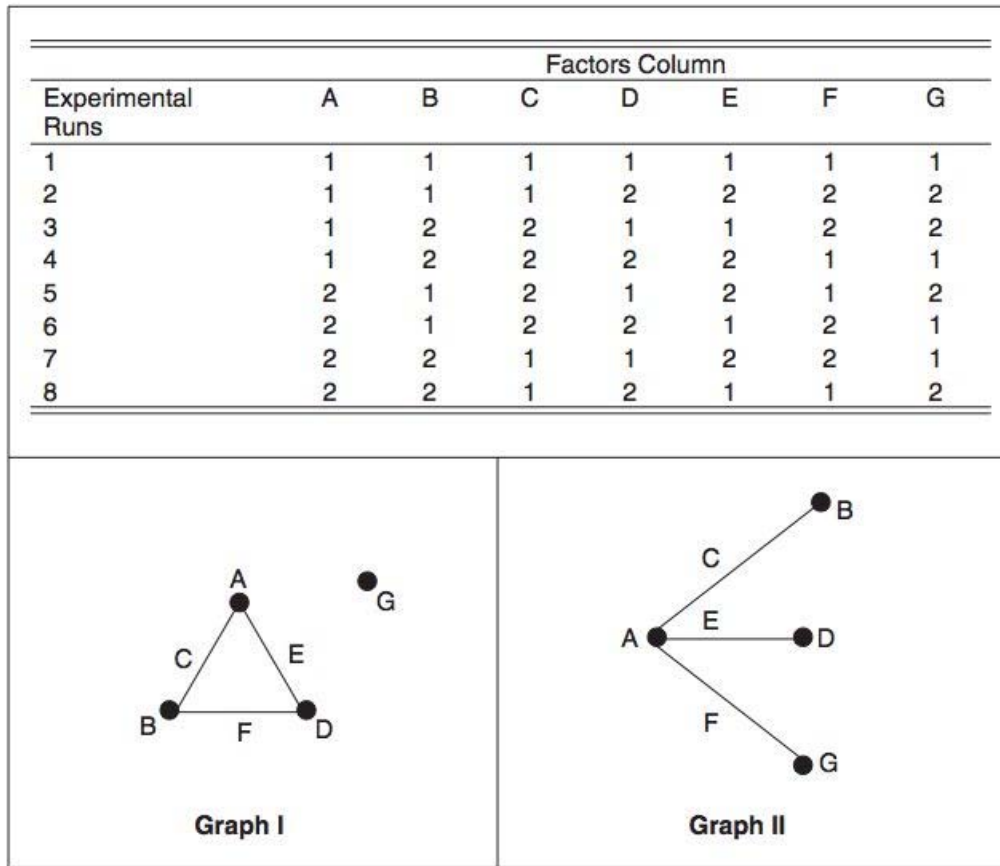


Figure 7.7. Example of an $L_8 (2^7)$ Orthogonal Array and Linear Graphs

orthogonal array without confounding the effects of the interactions with the effects of the individual factors being studied.

Figure 7.7 shows two linear graphs for the L_8 array. Graph II (on the right) shows the graph for the situation where all interactions of interest involve a common factor, A. Graph I (on the left) shows the graph for a design that requires the study of three interactions ($A \times B$, $B \times C$, and $A \times C$), involving the same three main effect factors (A, B, and C). No interaction effects involving G are included in this design.

The graphs are constructed of interconnecting dots, with each dot representing a column within the array in which a factor (main effect) can be assigned. The connecting line represents the interaction between the two dots (factors) at each end of the line segment. The number accompanying the line segment represents the column within the array to which the interaction should be assigned.

Dr. Taguchi's concept of robustness was earlier defined as the product or process performing consistently on target and is relatively insensitive to factors that are difficult to control. Robustness applies to both product and process. From a product standpoint, we can further define robustness as "the ability of the product to perform consistently as designed with minimal effect from changes in uncontrollable operating influences" (Peace, 1993, 5). For processes, we can define robustness as

“the ability of the process to produce consistently good product with minimal effect from changes in uncontrollable manufacturing influences” (Peace, 1993, 5). These definitions recognize that we cannot always control some of the things that create variation within the process or the product. Walter Shewhart referred to this as random or common variation and recognized its existence in all processes. Similar to Shewhart, Dr. Taguchi’s approach is to use designed experiments to identify and control those factors that are significant causes of variation and to do so in a way that minimizes the effect of those variables that cannot be controlled, or that it is not practical to control.

SUMMARY

This chapter has provided a brief overview of experimental design. Experimental design can be important in optimizing processes and solving problems. The different types and methodologies associated with experimental design were introduced in this chapter. Full-factorial designs permit the assessment of all main effects and all interaction effects at the expense of efficiency. To increase efficiency, screening experiments using fractional factorial designs can identify critical variables for further experimentation. ANOVA is used to analyze the data obtained from designed experiments. Genichi Taguchi’s contributions to the field of experimental design were discussed and his approach to DOE using orthogonal arrays was introduced.

DISCUSSION QUESTIONS

1. Discuss what is meant by factor, level, and treatment.
2. What is meant by the term replication? What role does it play in DOE?
3. Define and discuss the term blocking. When might blocking be useful?
4. Discuss the advantages and disadvantages of full-factorial design over one-factor-at-a-time experimentation.
5. What is meant by a 2^3 experimental design?
6. How is variance broken down in ANOVA?
7. How do Taguchi’s orthogonal arrays compare to full-factorial designs?
8. What is meant by the term orthogonal array?
9. Define and discuss Taguchi’s concept of robustness.
10. What is meant by the term interaction effect?
11. How might the use of fractional factorial designs be useful in increasing the efficiency of an experimental design?