Taguchi Techniques for Quality Engineering

Loss Function, Orthogonal Experiments, Parameter and Tolerance Design

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Taguchi Techniques for Quality Engineering

To Emily,
who is always first in my book

A chasm.
A bridge to build.
Not as a monument in itself,
but to make it easier for others to follow.

Preface

Taguchi Techniques for Quality Engineering is intended as a guide and reference source for industrial practitioners (managers, engineers, and scientists) involved in product or process experimentation and development. Most engineers are familiar with setting up tests to model actual field conditions and the cause-effect relationship of design to performance; however, their knowledge of a proper testing strategy is usually limited. When engineers have had exposure to experimental design, typically, the reaction is to deem the approach too costly and time consuming because of full factorial designs.

It is most unfortunate that people are not aware of the potential savings in test time and money offered by more efficient testing strategies. Not only are savings in test time and cost available but also a more fully developed product or process will emerge with the use of better experimental strategies.

The Taguchi philosophy provides two tenets: (1) the reduction in variation (improved quality) of a product or process represents a lower loss to society, and (2) the proper development strategy can intentionally reduce variation. Again, most managers and engineers are not aware of the economics of improved quality and the techniques to achieve higher quality at lower costs.

This book addresses the basic testing and development strategies that have allowed some Japanese companies to successfully become world economic competitors. Many Japanese engineers since the mid-1960s have had Taguchi training. In 1985 Nippon Denso, a Toyota affiliate, ran over 2500 experiments concerning automotive electrical products, for example.

By using and understanding the Taguchi methods, managers and engineers will realize what is required to put western product development and quality back into the competition. Today's managers and engineers must have a certain amount of exposure to these methods before they can appreciate how much improvement in testing and development strategies can be made. The text takes a user-oriented, hands-on approach for working engineers or scientists and their immediate management to develop initial expertise in the Taguchi methodology. There are currently few sources of information about Taguchi methods and these speak, typically, from a statistician's point of view. This book should be quite useful to the statistically inexperienced engineer who would have some difficulty understanding and utilizing a traditional text concerning designed experiments.

It is hoped that *Taguchi Techniques for Quality Engineering* will bridge the gap for the industrial user, eventually making American companies more competitive with their products in a world market. World-class quality will be a requirement for corporations to remain lucrative, let alone highly competitive, as more and more companies embrace the Taguchi methods.

My indebtedness is to Bill Diamond who introduced me to experimentation based on orthogonal arrays, the Hadamard matrices. I know he would hate to admit it, but the Taguchi matrices are mathematically and statistically equivalent to Hadamard's. The approaches used by the two experimenters may be different but the matrices are not.

I would like to give my thanks to Kathy Layne and Steve Abney, two very dear friends, who acted as statistical consultants, an editorial staff, and sympathetic ears during the creation of this text. My thanks also to those who suffered through some of the pilot classes and seminars on designed experiments; your contribution has been the engineer's point of view and, for me, a better appreciation of what the customer expects from this product. And lastly, thanks to my family for the tolerance of all the lost evenings and weekends as Dad lingered over the PC.

The author expresses gratitude to the American Supplier Institute, Inc., Center for Taguchi Methods, for granting permission to reproduce the orthogonal array, triangular table, and related linear graphs. They are contained in ASI's new (1987) edition of *Orthogonal Arrays and Linear Graphs*.

Phillip J. Ross

Introduction

Taguchi addresses quality in two main areas: off-line and on-line quality control (QC). Both of these areas are very cost sensitive in the decisions that are made with respect to the activities in each. Off-line QC refers to the improvement of quality in the product and process development stages. On-line QC refers to the monitoring of current manufacturing processes to verify the quality levels produced. The off-line portion of QC is addressed in this text because of the paucity of materials on this phase of Taguchi methods and the positive impact on cost that is obtained by improving quality at the earliest times in a product life cycle.

The on-line phase is covered by many texts as a dimensional approach to quality control, typified by statistical process control, or SPC, and for this reason will not be addressed in this text. The Taguchi on-line QC approach is a cost quality control perspective and some day should be recognized as an alternative quality control system.

This text reviews the basic aspects of off-line QC developed by Taguchi. There are several more sophisticated concepts for off-line QC that are not covered in this text but should be pursued by the experimenter after initial work with these methods. Also, education and training in general statistical methods is recommended. In particular other designed experiment texts will be valuable for the experimenter as background. A short description of the chapter contents follows.

Chapter 1. The Economics of Reducing Variation

The economics (cost reduction) of reducing variation is a subject that is not addressed widely at this time. Taguchi uses a different cost model for product characteristics than is typically used, which places more emphasis on reducing variation, particularly when the total product variation is within the specification limits for the product. This chapter covers the conventional viewpoint of cost versus specification limits and introduces the Taguchi model for cost versus specification limits, the loss function. The Taguchi methodology ascribes to the approach that the lowest loss to society represents the product with the highest quality. Higher product quality by definition means less variation of a product characteristic. The difference between conventional and Taguchi approaches to higher quality is that one proposes that higher quality costs more and the other proposes that higher quality costs less. The loss function is a mathematical way of quantifying the cost as a function of product variation which answers the question of whether further reduction of variation will reduce costs.

Also discussed is the difference between off-line and on-line QC and where the responsibility falls for that portion of total quality control. The different types of loss functions are described for the typical types of product characteristics such as higher is better, nominal is best, and lower is better.

Chapter 2. Introduction to Analysis of Variance

Chapter 2 introduces the basics of conducting an analysis of variance for a particular set of data and how the ANOVA techniques work from a statistical basis. The examples are extremely simple and easy to follow because the purpose of the book is to teach a graduate person the mechanics of ANOVA, not to practice basic arithmetic. The F test, a basic statistical test of comparisons of products, is introduced and explained in a simple manner as a tool to make decisions after an ANOVA is completed.

Chapter 3. Introduction to Orthogonal Arrays

Orthogonal arrays are introduced from the viewpoint of the pragmatist who is always trying to make product improvement decisions with the minimum amount of test data. Using minimal amount of test data is not necessarily a problem in itself; however, the considerations of what may make up a valid experiment from a risk viewpoint are seldom considered by the typical experimenter. The statistical aspects of the size of an experiment are discussed in conjunction with the amount of information required to be evaluated during the experiment. The aspects of designing a simple orthogonal experiment are discussed, including the handling of various factors and interaction effects. Also discussed are practical randomization techniques and how they apply to orthogonal array experimentation; a technique called *blocking*, which allows known sources of variation to be controlled in an experiment rather than depending upon randomization; and how to make an estimate of experimental error.

Chapter 4. Multiple-Level Experiments

Some special methods of modifying a two-level orthogonal array to accommodate multiple (more than two) level factors are introduced and limitations of each are discussed. Polynomial decomposition of variance is introduced with a discussion of what information is gained when running a multiple-level versus a two-level experiment.

Chapter 5. Interpretation of Experimental Results

Methods of estimating different values such as the percent contribution, the mean, and confidence intervals from the experimental data are discussed. Two methods of estimating the mean are used, standard and omega transformation. Other interpretation methods of lesser statistical sophistication are discussed also.

Chapter 6. Special Designs

A typical situation that confronts an engineer is handled with nested experiments. Many times discrete variables such as different materials cause a portion of the experiment to be unable to be exposed to the variation of other factors. This situation requires the use of a nested experiment to allow easy analysis of the data. Engineers will find themselves running into this fairly frequently. Two methods of handling a mixture of factors with different numbers of levels are covered and a component search technique is described for problems where retest is possible. Many nondestructive tests could benefit from this test strategy.

Chapter 7. Attribute Data

All of the problems discussed up to this point concerned variable data, which are on a continuous scale from high to low, such as weight, diameter, and voltage. However, some experiments do not lend themselves to this type of measurement system. Results are on a discontinuous scale such as good or bad, passing or failing, meets specification or doesn't meet specification. Such ratings become attribute characteristics and require a different type of analysis than variable data. The factors may be allocated to an experiment in the same manner, but the analysis can be modified for attribute data.

Chapter 8. Parameter and Tolerance Design

The main thrust of Taguchi methods is the use of parameter design which is the ability to design a product or process to be resistant to various environmental factors that change continuously with customer use. To determine the best design of a product or process requires the use of a strategically designed experiment which exposes the product or process to the varying environmental conditions. Taguchi refers to these variations in customer use as noise factors. The analysis of the experimental results uses a signal-to-noise ratio to aid in the determination of the best product or process designs. Nonlinear response characteristics of products or processes can be used to the engineer's advantage if the proper design philosophy is used.

Contents

Chapter

1

The Economics of Reducing Variation

1-1 The Meaning of Quality

Products have characteristics that describe their performance relative to customer requirements or expectations. Characteristics such as fuel economy of a car, the weight of a package of breakfast cereal, the power losses of a home hot water heater, or the breaking strength of fishing line are all examples of product characteristics that are of concern to customers at one time or another.

The quality of a product is measured in terms of these characteristics. Quality is related to the loss to society caused by a product during its life cycle. A truly high quality product will have a minimal loss to society as it goes through this life cycle. The loss a customer sustains can take many forms, but it is generally a loss of product function or properties. Other losses are time, pollution, noise, etc. If a product does not perform as expected, the customer senses some loss. After a product is shipped, a decision point is reached; it is the point at which the producer can do nothing more to the product. Before shipment the producer can use expensive or inexpensive materials, use an expensive or inexpensive process, etc.; but once shipped, the commitment is made for a certain product expense during the remainder of its life.

Quality has but one true evaluator, the customer. A "quality circle" that describes this situation is shown in Figure 1-1. The customer is judge, jury, and executioner in this model. Customers vote with their wallets on which products meet their requirements, including price and performance. The birth of a product, if you will, is when a designer takes information from the customer (market) to define what the customer wants, needs, and expects from a particular product. Sometimes, a new idea (high technology) creates its own market, but once a competitor can duplicate the product, the technological advantage is lost.

The designer must take the customer's wants, needs, and expectations and translate them into product specifications, which include drawings, dimensions, tolerances, materials, processes, tooling, and gaging. The makers use this information, along with the prescribed machinery, to fabricate the product. The product is then delivered via marketing channels to the customer. To satisfy the customer the product must arrive in the right quantities, at the right time, at the right place, and provide the right functions for the right period of time. All of this must be available to the customer at the right price, too. This is a tough order to fill, but the simplest definition of high quality is a happy customer. Customers should become more endeared to a product the more it is used. Customer feedback to the designers and makers comes in terms of the number of products sold and the warranty, repair, and complaint rate. Increasing sales volume and market share with low warranty, repair, or complaint rates translates to happy customers.

1-2 Goalpost Philosophy

Today in America it is quite popular to take a very strict view of what constitutes quality. In his book, Crosby supports the position that a product made according to the print, within permitted tolerance, is of

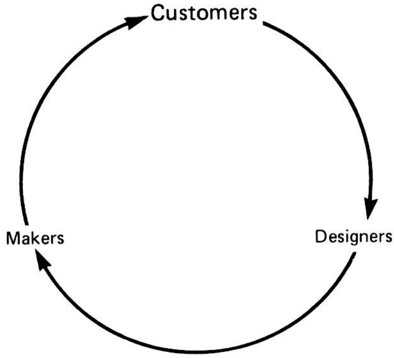

Figure 1-1 Quality circle.

high quality.* This strict viewpoint embraces only the designers and the makers. This is the "goalpost" syndrome.† What is missing from this philosophy is the customer's requirements. A product may meet print specifications, but if the print does not meet customer requirements, then true quality cannot be present. For example, customers buy TVs with the best picture, not ones that necessarily meet specifications.

Another example showing that the goalpost syndrome contradicts the customer's desires is as follows. Batteries supply a voltage to a light bulb in a flashlight. There is some nominal voltage, let us say 3 volts, that will provide the brightest light but will not burn out the bulb prematurely. Customers want the voltage to be as close to the nominal voltage as possible, but battery manufacturers may be using a wider tolerance than allowed by the battery specification. So, as a result, some flashlights burn dimly and others burn out the bulbs prematurely. Customers want the product close to nominal all the time, and producers want to allow the product to vary to the limit of the specifications; how can these seemingly incongruent ideas be brought into harmony?

1-3 Taguchi Loss Function

The Taguchi loss function recognizes the customer's desire to have products that are more consistent, part to part, and a producer's desire to make a low-cost product. The loss to society is composed of the costs incurred in the production process as well as the costs encountered during use by the customer (repair, lost business, etc.). To minimize the loss to society is the strategy that will encourage uniform products and reduce costs at the point of production and at the point of consumption. Let's look at a comparison of the goalpost and loss function philosophies with an example.

1-4 Comparison of Philosophies

When the hood of a typical automobile is opened, a mechanism may be in place which automatically holds the hood in the open position. The force required to close the hood from this position is important to the customer. If the force is too high, then a weaker individual may have difficulty in closing the hood and ask for the mechanism to be adjusted. If the force is too low, then the hood may come down when a gust of wind hits it, and again the customer will ask for it to be adjusted. The engineering specifications and detail and assembly drawings call out a

*Philip B. Crosby, *Quality Is Free*. McGraw-Hill, New York, 1979.

†In football, a team is awarded three points for a field goal regardless of where the ball passes through the uprights, whether exactly midway between the uprights or far to left or right. In other words, there is a wide tolerance.