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ABSTRACT

Interest in Total Quality Management (TQM) at institutions of higher education has been stressed in recent years as an important area of activity for institutional researchers. Two previous AIR Forum papers have presented some of the statistical and graphical methods used for TQM. This paper, the third in the series, first discusses some of the statistical and graphical methods used by practitioners of Total Quality Management but which are also useful to institutional research in general. It then introduces Taguchi methods of evaluation, including information on the availability of supporting computer software programs. The concept of "conversational" as opposed to "listening" or passive statistical and graphical techniques is pursued. In particular, the paper considers general statements about experimental designs by noting a case study (a manufacturing application) and including some factorial designs using the Taguchi methodology of orthogonal arrays. Supportive computer software designed for use in developing and analyzing experimental designs, Taguchi methods, and their associated graphics are identified. Contains 24 references. (GLR)

TOTAL QUALITY MANAGEMENT:

STATISTICS AND GRAPHICS III - EXPERIMENTAL DESIGN AND TAGUCHI METHODS

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Jean Endo
Chair and Editor
Forum Publications
Editorial Advisory Committee

Abstract

The application of Total Quality Management (TQM) has been stressed in recent years as an important area of activity for institutional researchers. Its growing importance was reinforced in fall of 1991 by the devotion of an issue of New Directions for Institutional Research to TQM. Two previous AIR papers have presented some of the statistical and graphical methods needed for TQM but which also have other useful applications for institutional research. This paper: 1) extends the discussion of experimental design techniques; 2) introduces Taguchi methods and 3) notes the availability of supporting computer software.

Introduction

Interest in Total Quality Management (TQM) at institutions of higher education has been stressed in recent years as an important area of activity for institutional researchers. The initial discussion was introduced by Lawrence Sherr at the 29th Annual AIR Forum (Sherr, 1989). The devotion of an issue of New Directions for Institutional Research (Sherr & Teeter, 1991) entitled: "Total Quality Management in Higher Education" also illustrates this interest. Further, many special interest groups have come into being in higher education circles including electronic mail postings, for example, TQM-L at the University of Kansas.

This paper is the third in a series discussing some of the statistical and graphical methods available from the disciplines of quality control but useful to institutional research in general. The first paper (Schwabe, 1991) presented at the 31st Annual AIR Forum considered: 1) cause-and-effect diagrams; 2) Pareto diagrams and 3) control charts. The first two techniques and other graphically oriented ones are also available in Sherr and Teeter (1991) and Spanbauer (1992). For a more engineering discussion see Montgomery (1991b). The second paper (Schwabe &

Cherland, 1992) was given last year with a colleague, Ryan Cherland, at the 32nd Annual AIR Forum. It also discussed control charts and introduced experimental design. The impetus for the series arose from the address by Sherr mentioned above. The aim of these presentations is twofold: 1) to provide a discussion of some of the statistical and graphical tools used by practitioners of TQM and 2) to introduce techniques which are new to many of us in the field of institutional research and may be of general usefulness.

The statistical basis of quality control and related activities is stressed by leaders in the field including W. Edwards Deming (1986). Also, as noted by Ryan (1989, p. 285) when he introduced the concepts of experimental design, many users of statistical quality control in the early 1980's began to look for techniques which they considered as "conversational" to supplement the above "listening" or passive statistical and graphical tools. Further support of the use of experimental design techniques was given by Dr. Genichi Taguchi, when he began to introduce his ideas and methods in the United States in 1980 (Kapur, 1991).

Experimental Design

The classic text for a discussion of experimental design is by Box, Hunter and Hunter (1978). More recent books are by Ryan (1989) which is specifically orientated toward quality control and again with an engineering flavor (Montgomery, 1991a).

Some experimental design techniques are illustrated below in a case study arising from a manufacturing application. While the institutional researcher does not usually have the opportunity to create a classical experimental design, it is clear that in industrial settings similar constraints prevail including time, cost, and interference with an ongoing process. Similar ideas and conditions are discussed by Bernard Yancey (1988) in the first chapter entitled "Institutional Research and the Classical Experimental Paradigm".

In a recent article, Ophir, El-Gad and Snyder (1988) give a case study for the improvement of a manufacturing process. It is a compact discussion which uses several techniques of interest to us. For our purposes, most of its technical engineering terminology have been removed. The problem was to determine the cause of one type of failure in the manufacturing of an item resulting in the loss of tens of thousands of dollars due to scrap. A team was formed including a statistician to consider the problem and define its various tasks. One such task was clarification of the meaning of failure and its range of measurements. This was done by developing histograms illustrating the range of values used to measure both accepted and rejected items. Several causes of failure were identified and analyzed by a Pareto diagram. Two causes were found to be significant, but one was easily rectified and therefore dropped from further analysis. The other major cause of failure was analyzed by a classification of the possible factors causing it to occur. This analysis was made in the format of an Ishikawa fishbone or cause-and-effect diagram. The diagram included the four categories: 1) Operators, 2) Equipment, 3) Materials, and 4) Methods.

Both sufficient training and sufficient carefulness when performing the tasks involved were considered for the operators. The three types of equipment were noted including eleven specific possible causes of the failure. For materials, six possible causes were given. And lastly, four areas of concern were listed under methods. From these 23 possible causes of failure, seven were chosen as most promising to pursue via the methodologies of experimental design. Since each of these seven selected factors were known to have exactly two possible values, a full factorial design would entail 2^7 or 128 combinations or runs in each experiment. It was deemed too costly to make the required 128 runs. Of course, fewer runs could be performed by choosing one of many techniques for reducing the number of tests or experiments, and still examine the full seven factors. These techniques are subsumed under the rubric of fractional factorial designs in such texts as Box, Hunter and Hunter (1978 p. 374) and Ryan (1989 p. 331). However, none of these approaches were chosen because several team participants and some members of management were skeptical about the entire approach of designed experiments. Consequently, a more modest approach was taken initially by holding four of the seven factors constant and varying the remaining three for a 2^3 or 8 run design.

The sample size, n, for each run was chosen by using the binomial distribution where p was the current proportion of defective products and d the smallest change in the proportion that is to be considered significant at the 5% significance level. That is: $n > 8pq/d^2$. This yielded a sample size of 75, but for economic and timing purposes a sample size of 50 was usedfor a total of 400 items for the full experiment. The results of this first experiment indicated that the current manufacturing procedure was the worst case with a run of 4.9 percent defective and that the value of one of the factors or possible cause of failure had no effect on the outcome. In addition, several runs produced zero defects. Because of the success of this experiment, two subsequent experiments were made resulting in a final savings of eight times the cost of the experimentation each year thereafter. In fact, since the study took only three months to complete, savings accrued during the first year as well.

Taguchi Methods

The Taguchi approach to quality control is quite controversial and consequently has both strong advocates and adversaries. One proponent, Roy (1990, pp. 17-18) defines some of the appeal of the Taguchi approach to include: upfront improvement; loss function; team approach and brainstorming; consistency in the design of experiments; reduction of time and cost of experiments; robustness; reduction of variation; and the reduction of service costs. For the purpose of this discussion, only 1) the loss function and 2) the approach to experimental design will be considered.

In Chapter 2 of Ryan (1988 p. 11), Diane Byrne asserts that:

> Fundamental to Dr. Genuichi Taguchi's approach to Quality Engineering is the concept of loss. When we think of loss to society, things that come to mind include air pollution, excessive noise from a car without a muffler, or a chemical leak from a nuclear power plant. Dr. Taguchi views loss to society on a much broader scale. He associates loss with every product that meets the consumer's hand. This loss includes, among other things, consumer dissatisfaction, added warranty costs to the producer, and loss due to a company's having a bad reputation, which leads to eventual loss of market share.

Roy (1990, p. 10) quantifies the loss function to be the dollar value that is directly proportional to the square of the distance that a product is from its targeted or expected value. This is in contrast to the usual approach which does not define loss until the product fails completely, hence the loss is 100 percent of the product's value. This is shown graphically as Figure 1.

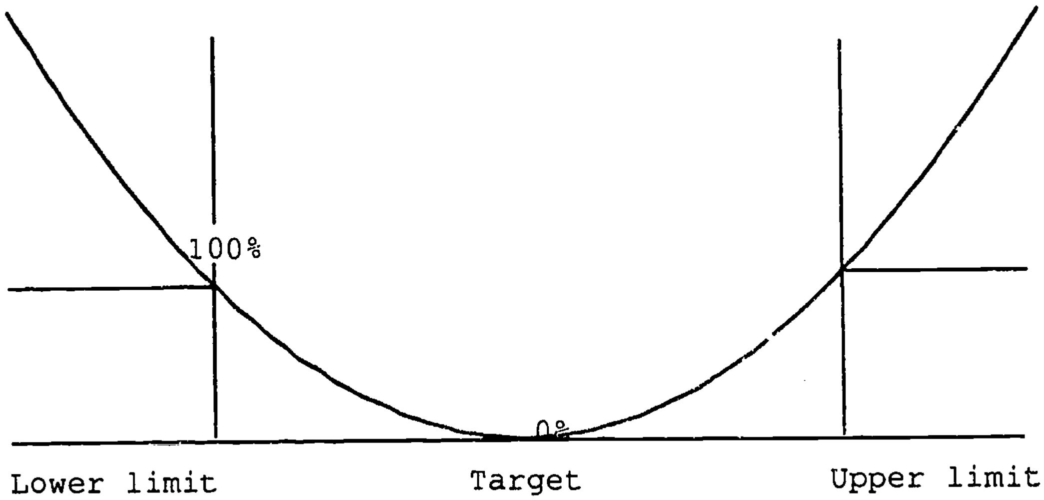

Figure 1 Taguchi's Loss Function

As he begins his discussion of Taguchi's approach to experimental design, Roy (1990 p. 32) continues with:

> The experimental efficiency Taguchi offers can be described using the following analogy. Assume that you are asked to catch a big fish from a lake with a circular net. You are also told that the fish usually stays around its hideout. But you have no knowledge of where this place is. How do you go about catching the fish? Thinking analytically you may first calculate the area of the net and the lake, then layout an elaborate scheme to cover the entire lake. You may find, after all

> this planning, that you need the whole day to locate the spot where the fish is. Wouldn't it be nice to have a fish finder that could tell you the approximate locations where to throw your net. The Taguchi approach in experimental studies, to a great extent, works like a fish finder. It tells you which areas to try first and then from the results of trials, you determine, with a high degree of certainly, the most probable location of the fish.

This methodology falls within the area of fractional factorial design, that is, choosing a design that minimizes the number of runs in the experiment. Taguchi uses the concept of an orthogonal array to simplify and standardize his choice of such a design. An example of an orthogonal array is Taguchi's L_8 array as shown in Table 1 (Roy, 1990 p. 43). A discussion of the mathematical and statistical basis of orthogonal arrays is given by Kacker et al. (1990) and (1991). A more general and complete discussion of factorial designs is found in Raktoe et al. (1981).

Table 1 Taguchi's L_8 Orthogonal Array

Runs	Factors 1	2	3	4	5	6	7
1	1	1	1	1	1	1	1
2	1	1	1	2	2	2	2
3	1	2	2	1	1	2	2
4	1	2	2	2	2	1	1
5	2	1	2	1	2	1	2
6	2	1	2	2	1	2	1
7	2	2	1	1	2	2	1
8	2	2	1	2	1	1	2

The orthogonal array displayed in Table 1 determines the value of each factor for a given run.

In Table 2 (Roy, 1990 p. 42) indicates the difference in the number of runs for a given experiment that need to be performed using the classical factorial approach versus the Taguchi approach. It is clear that there is a significant difference in the number of runs necessary between the two methods.

Table 2 Comparison of Factorial Design and Taguchi Design

		Factorial	Taguchi
Factors	Levels	Number of Runs	Number of Runs
2	2	4 (2^2)	4
3	2	8 (2^3)	4
4	2	16 (2^4)	8
7	2	128 (2^7)	8
15	2	32,768 (2^{15})	16
4	3	81 (3^4)	9

In Ryan (1989 chap. 14) a discussion contrasting the two methods centers on the L_8 array. He also asserts the need to carefully consider all possible factors and not simplify the design too early in the analysis. However, in the introduction to his computer software package for handling Taguchi experimental design, Roy (1991) asserts that a strength of the method is its standard or "cook book" approach versus other methods that are not standardized.

Computer Support

The availability of both commercial and public domain software for developing and analyzing experimental designs, Taguchi methods, and their associated graphics are available in various forms. Many program listings are found in journal articles or books. Some are available on an accompanying diskette such as with Heiberger (1989). Useful comments about the use of the Heiberger book are made by Velleman (1991). An older work by Nachtsheim (1987) discusses some fifteen packages ranging from $25 to $34,000 for personal computer, minicomputer, or mainframe applications.

Three packages have come to my attention which are available on IBM compatible personal computers. The first supports some of the requirements for TQM short of control charts. It is a package entitled "SPC EXpert" available from Shewhart (1993). In addition, Shewhart indicates that he intends to add a windows environment with: a) flowcharting, b) fish-bone diagrams, c) cause and effect diagrams, and d) organization charts to better support the needs of TQM practitioners.

The second package is provided by the Institute of Japanese Union of Scientists and Engineers (1992) in three modules: JUSE-QCAS I including cause and effect diagrams, histograms, control charts, scatter diagrams, regression analysis, pareto diagrams, binomial probability, normal probability, Weibull probability and radar charts; JUSE-QCAS II including ANOVA, experimental design and orthogonal arrays; and JUSE-QCAS III including hypothesis/estimate test, multiple/polynomial regression analysis and many others. These modules are available separately or as a complete package. An illustrative demonstration diskette is available.

The third software package is available from Ranjit Roy (1991) which supports his book, Roy (1990) and deals with Taguchi methods. The demonstration diskette allows for experimentation with L_8 designs and gives completed examples of other designs.

Conclusion

The aim of this third paper in a series was to continue the twofold purpose of the previous two by: 1) providing a discussion of some of the statistical and graphical tools used by practitioners of TQM and 2) introducing techniques which are new to many of us in the field of institutional research and may be of general usefulness. The concept of "conversational" as opposed to "listening" or passive statistical and graphical techniques appears to be of interest to TQM as "continual improvement" is pursued. In particular, this paper considered general statements about experimental designs by noting a case study and including some fractional factorial designs using the Taguchi methodology of orthogonal arrays. Additionally, several computer software packages were mentioned that are supportive of the above statistical and graphical methodologies.

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