ISSN 2349-6193
Impact Factor: 2.243

IJESMR
International Journal OF Engineering Sciences & Management Research

TAGUCHI'S METHOD AND THEIR APPLICATIONS -- A REVIEW

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DOI: 10.5281/zenodo.58949

Keywords: Tauchimethod, machining, performance, quality, and cost

ABSTRACT
Genichi Taguchi has made valuable contributions to statistics and engineering. His emphasis on loss to society, techniques for investigating variation in experiments, and his overall strategy of system, parameter and tolerance design have been influential in improving manufactured quality worldwide. Although some of the statistical aspects of the Taguchi methods are disputable, there is no dispute that they are widely applied to various processes.

INTRODUCTION
Every experimenter has to plan and conduct experiments to obtain enough and relevant data so that he can infer the science behind the observed phenomenon. He can do so by, TRIAL-AND-ERROR APPROACH : performing a series of experiments each of which gives some understanding. This requires making measurements after every experiment so that analysis of observed data will allow him to decide what to do next - "Which parameters should be varied and by how much". Many a times such series does not progress much as negative results may discourage or will not allow a selection of parameters which ought to be changed in the next experiment. Therefore, such experimentation usually ends well before the number of experiments reach a double digit! The data is insufficient to draw any significant conclusions and the main problem (of understanding the science) still remains unsolved.[3]
The goal of any experimental activity is to get the maximum realistic information about a system. It is not always true that higher number of measurements will give maximum realistic information. Larger the number of measurements, huge will be the total error that enters into the measurement equation. Larger number of measurements lead to more costly experimentation. It is important to obtain maximum realistic information with the minimum number of well-designed experiments. An experimental program recognizes the major "factors" that affect the outcome of the experiment. The factors may be identified by looking at all the quantities that may affect the outcome of the experiment.

TAGUCHI METHOD
Genichi Taguchi, Japanese engineer and statistician, began formulating the Taguchi Method while developing a telephone-switching system for Electrical Communication Laboratory, a Japanese company, in the 1950s. As a result of his success, he eventually became well-known in both Japan and the United States, with companies such as Toyota, Ford, Boeing and Xerox adopting his methods. An approach to engineering that emphasizes the roles of research and development, product design and product development in reducing the occurrence of defects and failures in products. The Taguchi method considers design to be more important than the manufacturing process in quality control and tries to eliminate variances in production before they can occur.In statistics, fractional factorial designs are experimental designs consisting of a carefully chosen subset (fraction) of the experimental runs of a full factorial design. The subset is chosen so as to exploit the sparsity-of-effects principle to expose information about the most important features of the problem studied, while using fraction of the effort of a full factorial design in terms of experimental runs and resources.Fractional designs are expressed using the notation lk − p, where l is the number of levels of each factor investigated, k is the number of factors investigated, and p describes the size of the fraction of the full factorial used. Formally, p is the number of generators, assignments as to which effects or interactions are confounded, i.e., cannot be estimated independently of each other (see below). A design with p such generators is a 1/(lp) fraction of the full factorial design.[5]For example, a 25 − 2 design is 1/4 of a two level, five factor factorial design. Rather than the 32 runs(2**5=32) that would be required for the full 25 factorial experiment, this experiment requires only eight runs(2**(5-2))=8In practice, one rarely encounters l > 2 levels in fractional factorial designs, since response surface methodology is a much more experimentally efficient way to determine the relationship between the

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experimental response and factors at multiple levels. In addition, the methodology to generate such designs for more than two levels is much more cumbersome. The levels of a factor are commonly coded as +1 for the higher level, and −1 for the lower level. For a three-level factor, the intermediate value is coded as 0.

LOSS FUNCTIONS

LOSS FUNCTIONS IN STATISTICAL THEORY

Traditionally, statistical methods have relied on mean-unbiased estimators of treatment effects: Under the conditions of the Gauss-Markov theorem, least squares estimators have minimum variance among all mean-unbiased estimators. The emphasis on comparisons of means also draws (limiting) comfort from the law of large numbers, according to which the sample means converge to the true mean. Fisher's textbook on the design of experiments emphasized comparisons of treatment means.

Gauss proved that the sample-mean minimizes the expected squared-error loss-function (while Laplace proved that a median-unbiased estimator minimizes the absolute-error loss function). In statistical theory, the central role of the loss function was renewed by the statistical decision theory of Abraham Wald.

TAGUCHI'S USE OF LOSS FUNCTIONS

Taguchi knew statistical theory mainly from the followers of Ronald A. Fisher, who also avoided loss functions. Reacting to Fisher's methods in the design of experiments, Taguchi interpreted Fisher's methods as being adapted for seeking to improve the mean outcome of a process. Indeed, Fisher's work had been largely motivated by programmes to compare agricultural yields under different treatments and blocks, and such experiments were done as part of a long-term programme to improve harvests.

However, Taguchi realised that in much industrial production, there is a need to produce an outcome on target, for example, to machine a hole to a specified diameter, or to manufacture a cell to produce a given voltage. He also realised, as had Walter A. Shewhart and others before him, that excessive variation lay at the root of poor manufactured quality and that reacting to individual items inside and outside specification was counterproductive.

He therefore argued that quality engineering should start with an understanding of quality costs in various situations. In much conventional industrial engineering, the quality costs are simply represented by the number of items outside specification multiplied by the cost of rework or scrap. However, Taguchi insisted that manufacturers broaden their horizons to consider cost to society. Though the short-term costs may simply be those of non-conformance, any item manufactured away from nominal would result in some loss to the customer or the wider community through early wear-out; difficulties in interfacing with other parts, themselves probably wide of nominal; or the need to build in safety margins. These losses are externalities and are usually ignored by manufacturers, which are more interested in their private costs than social costs. Such externalities prevent markets from operating efficiently, according to analyses of public economics. Taguchi argued that such losses would inevitably find their way back to the originating corporation (in an effect similar to the tragedy of the commons), and that by working to minimise them, manufacturers would enhance brand reputation, win markets and generate profits.

Such losses are, of course, very small when an item is near to negligible. Donald J. Wheeler characterised the region within specification limits as where we deny that losses exist. As we diverge from nominal, losses grow until the point where losses are too great to deny and the specification limit is drawn. All these losses are, as W. Edwards Deming would describe them, unknown and unknowable, but Taguchi wanted to find a useful way of representing them statistically. Taguchi specified three situations:

1. Larger the better (for example, agricultural yield);
2. Smaller the better (for example, carbon dioxide emissions); and
3. On-target, minimum-variation (for example, a mating part in an assembly).

The first two cases are represented by simple monotonic loss functions. In the third case, Taguchi adopted a squared-error loss function for several reasons:

- It is the first "symmetric" term in the Taylor series expansion of real analytic loss-functions.
- Total loss is measured by the variance. As variance is additive (for uncorrelated random variables), the total loss is an additive measurement of cost (for uncorrelated random variables).
- The squared-error loss function is widely used in statistics, following Gauss's use of the squared-error loss function in justifying the method of least squares.

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RECEPTION OF TAGUCHI'S IDEAS BY STATISTICIANS

Though many of Taguchi's concerns and conclusions are welcomed by statisticians and economists, some ideas have been especially criticized. For example, Taguchi's recommendation that industrial experiments maximisesome signal-to-noise ratio (representing the magnitude of the mean of a process compared to its variation) has been criticized widely.

In practice, one rarely encounters l > 2 levels in fractional factorial designs, since response surface methodology is a much more experimentally efficient way to determine the relationship between the experimental response and factors at multiple levels. In addition, the methodology to generate such designs for more than two levels is much more cumbersome.

The levels of a factor are commonly coded as +1 for the higher level, and −1 for the lower level. For a three-level factor, the intermediate value is coded as 0.

In practice, experimenters typically rely on statistical reference books to supply the "standard" fractional factorial designs, consisting of the principal fraction. The principal fraction is the set of treatment combinations for which the generators evaluate to + under the treatment combination algebra. However, in some situations, the experimenter may take it upon himself or herself to generate his own fractional design.

A fractional factorial experiment is generated from a full factorial experiment by choosing an alias structure. The alias structure determines which effects are confounded with each other. For example, the five factor 25 − 2 can be generated by using a full three factor factorial experiment involving three factors (say A, B, and C) and then choosing to confound the two remaining factors D and E with interactions generated by D = A*B and E = A*C. These two expressions are called the generators of the design. So for example, when the experiment is run and the experimenter estimates the effects for factor D, what is really being estimated is a combination of the main effect of D and the two-factor interaction involving A and B.

An important characteristic of a fractional design is the defining relation, which gives the set of interaction columns equal in the design matrix to a column of plus signs, denoted by I. For the above example, since D = AB and E = AC, then ABD and ACE are both columns of plus signs, and consequently so is BDCE. In this case the defining relation of the fractional design is I = ABD = ACE = BCDE. The defining relation allows the alias pattern of the design to be determined.

OFF-LINE QUALITY CONTROL

Taguchi's rule for manufacturing.

Taguchi realized that the best opportunity to eliminate variation is during the design of a product and its manufacturing process. Consequently, he developed a strategy for quality engineering that can be used in both contexts. The process has three stages:

1. System design
2. Measure design
3. Tolerance design

SYSTEM DESIGN

This is design at the conceptual level, involving creativity and innovation.

PARAMETER DESIGN

Once the concept is established, the nominal values of the various dimensions and design parameters need to be set, the detail design phase of conventional engineering. Taguchi's radical insight was that the exact choice of values required is under-specified by the performance requirements of the system. In many circumstances, this allows the parameters to be chosen so as to minimize the effects on performance arising from variation in manufacture, environment and cumulative damage. This is sometimes called robustification.

TOLERANCE DESIGN

With a successfully completed parameter design, and an understanding of the effect that the various parameters have on performance, resources can be focused on reducing and controlling variation in the critical few dimensions (see Pareto principle).

LITERATURE SURVEY

A quick search in related journals, as well as the World Wide Web, reveals that the method is being successfully implemented in diverse areas, such as the design of VLSI; optimization of communication & information

 ISSN 2349-6193
Impact Factor: 2.243

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networks, development of electronic circuits, laser engraving of photo masks, cash-flow optimization in banking, government policymaking, runway utilization improvement in airports, and even robust eco-design.
GuruvaiahNaidu,Venkata Vishnu, JanardhanaRaju used Taguchi's robust design methodology and to develop the prediction models for surface roughness considering the control factors. Taguchi method is used to determine the optimum cutting milling parameters more efficiently. Four control factors viz. cutting speed, feed rate, depth of cut and coolant flow are investigated at three different levels. The work piece material used is EN-31 steel alloy. [1](2014)

MurahariKolli, Adepu Kumar employed Taguchi method to optimize the surfactant and graphite powder concentration in dielectric fluid for the machining of Ti-6Al-4V using Electrical Discharge Machining (EDM). The process parameters such as discharge current, surfactant concentration and powder concentration were changed to explore their effects on Material Removal Rate (MRR), Surface Roughness (SR), Tool wear rate (TWR) and Recast Layer Thickness (RLT)[2] (2015)

VishwajeetN.Rane1,Prof.AjinkyaP.Edlabadkar,Prof.PrashantD.Kamble&Dr.SharadS.Chaudhari used Taguchi method to obtain to optimize process parameter such as cutting speed, feed, and point angle. Taguchi methods are widely used for design of experiments and analysis of experimental data for optimization of processing conditions [3](2015)

Snehil A. Umredkar1, YashParikhused Taguchi method the control parameters for grinding process are optimized for reduction in cycle time while maintaining quality standards in a bearing manufacturing company.[4](2015)

D. Ahmadkhaniha, M. HeydarzadehSohi, A. Zarei-Hanzaki, S.M. Bayazid, M. Saba applied to determine the most influential controlling parameters of FSP such as tool rotational speed, travel speed, tilt angle and penetration depth on hardness value of Mg[5](2015)

Prakash Kumar Sahu, Sukhomay Pal optimized the process parameter to get the better mechanical properties of friction stir welded AM20 magnesium alloy using Taguchi Grey relational analysis (GRA)[6] (2015)

M. S. Sukumar, P. VenkataRamaiah, A. Nagarjuna has been used Taguchi Method to identify the optimal combination of influential factors in the milling process. Milling experiment has been performed on Al 6061 material, according to Taguchi orthogonal array (L16) for various combinations of controllable parameters viz. speed, feed and depth of cut[7](2014).

ResitUnal and Edwin B. Dean Using Taguchi methods for improving quality and reducing cost, describe the current state of applications and its role in identifying cost sensitive design parameters. In recognizing the need to reduce cost and improve quality and productivity. [8](2014)

SrinivasAthreya, DrY.D.Venkatesh approach to optimize the process parameters and improve the quality of components that are manufactured. The objective of this study is to illustrate the procedure adopted in using Taguchi Method to a lathe facing operation. [9](2014)

Mahendra G. Rathi, Nilesh A. Jakhadeused Taguchi method to obtain the optimal setting of forging process parameters in order to reduce the rejection rate due to unfilling defect. Initially, the various forging defects that occur in the components during closed-die hot forging process are investigated. [10] (2014)

AmiteshGoswami, Jatinder Kumar investigated surface integrity, material removal rate and wire wear ratio of Nimonic 80A using WEDM process. Taguchi's design of experiments methodology has been used for planning and designing the experiments. All of the input parameters and two factors interactions have been found to be statically significant for their effects on the response of interest. [11](2014)

MohdYazida, J. KhairurRijalb, M. S. Awaluddinb, EmeliaSaric deals with unsystematic pattern recognition system based historical data caused the industrial practitioners failed to predict in a short time either the part can be rejected or remanufactured. [12](2014)

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IkuoTanabea Hideki Sakamoto and KazuhideMiyamoto used Taguchi-methods to decide optimum processing conditions with narrow dispersion for robust design. The software for innovative tool using Taguchi-methods is developed and evaluated. There are two trials in the innovative tool using Taguchi-methods; First trial is accomplished for selecting important control factors and its optimum region, and Second trial decides the optimum combination of the control factors by more detail trial sing only important control factor[13](2014)

VijayKumar S. Jattia, MeenaLaadb, T.P.Singhc applied Taguchi methodology for depositing diamond-like carbon (DLC) films on P-type silicon substrates using inductively coupled plasma enhanced chemical vapor deposition (IC-PECVD) process. The Taguchi method is used to formulate the experimental layout, to analyze the effect of each process parameter and to predict the optimal choice for each process parameters such as bias voltage, bias frequency, deposition pressure and gas composition.[14](2014)

CONCLUSION

Taguchi's Method of parameter design can be performed with lesser number of experimentations as compared to that of full factorial analysis and yields similar results. Taguchi's method can be applied for analyzing any other kind of problems. The parameter design of the Taguchi method provides a simple, systematic, and efficient methodology for optimizing the process parameter .The Taguchi method emphasizes pushing quality back to the design stage, seeking to design a product/process which is insensitive or robust to causes of quality problems. It is a systematic and efficient approach for determining the optimum experimental configuration of design parameters for performance, quality, and cost. Principal benefits include considerable time and resource savings; determination of important factors affecting operation, performance and cost; and quantitative recommendations for design parameters which achieve lowest cost, high quality solutions.

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ISSN 2349-6193
Impact Factor: 2.243

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