2.1 SOME BASIC CONCEPTS

Robust design is an important methodology for improving product manufacturability and life, and for increasing manufacturing process stability and yield. Since its introduction to U.S. industry in 1980, Taguchi's approach to quality engineering and robust design has received much attention from designers, manufacturers, statisticians, and quality professionals.

Essentially, the central idea in robust design is that variations in a product's performance can inevitably result in poor quality and monetary losses during the product's life span. The sources of these variations can directly be classified into the two categories of controllable and uncontrollable or noise parameters. For instance, in a typical design application, factors such as geometric dimensions of a part can easily be controlled by designers. Uncontrollable or noise factors such as environmental variables, product deterioration or manufacturing imperfections, on the other hand, are also sources of variations whose effects can not be eliminated. Therefore, robust designs main function is to reduce a product's variation by reducing the sensitivity of the product to the sources.
of variation rather than by controlling these sources. In other words, robust design reduces response variation by selecting appropriate settings for controllable parameters as to dampen the effects of hard-to-control noise variables. This is the crux of off-line quality control. Taguchi's Methodology for implementing robust design is essentially a four-step procedure.

After WWII Japanese manufacturers were struggling to survive with very limited resources. If it were not for the advancements of Taguchi the country might not have stayed afloat let alone flourish as it has. Taguchi revolutionized the manufacturing process in Japan through cost savings. He understood, like many other engineers, that all manufacturing processes are affected by outside influences, noise. However, Taguchi realized methods of identifying those noise sources which have the greatest effects on product variability. His ideas have been adopted by successful manufacturers around the globe because of their results in creating superior production processes at much lower costs.

Here are some of the major contributions that Taguchi has made to the quality improvement world:

1. **The Loss Function** - Taguchi devised an equation to quantify the decline of a customer's perceived value of a product as its quality declines. Essentially, it tells managers how much revenue they are losing because of variability in their production process. It is a powerful
tool for projecting the benefits of a quality improvement program. Taguchi was the first person to equate quality with cost.

2. Orthogonal Arrays and Linear Graphs - When evaluating a production process analysis will undoubtedly identify outside factors or noise which cause deviations from the mean. Isolating these factors to determine their individual effects can be a very costly and time consuming process. Taguchi devised a way to use orthogonal arrays to isolate these noise factors from all others in a cost effective manner.

3. Robustness - Some noise factors can be identified, isolated and even eliminated but others cannot. For instance it is too difficult to predict and prepare for any possible weather condition. Taguchi therefore referred to the ability of a process or product to work as intended regardless of uncontrollable outside influences as robustness. He was pivotal in many companies' development of products and processes which perform uniformly regardless of uncontrollable forces; an obviously beneficial service.
Taguchi Methods is a system of cost-driven quality engineering that emphasizes the effective application of engineering strategies rather than advanced statistical techniques. It includes both upstream and shop-floor quality engineering. Upstream methods efficiently use small-scale experiments to reduce variability and find cost-effective, robust designs for large-scale production and the marketplace. Shop-floor techniques provide cost-based, real-time methods for monitoring and maintaining quality in production. Taguchi Methods allow a company to rapidly and accurately acquire technical information to design and produce low-cost, highly reliable products and processes. Its most advanced applications
allow engineers to develop flexible technology for the design and production of families of high quality products, greatly reducing research, development, and delivery time. In general, the farther upstream a quality method is applied, the greater leverage it produces on the improvement, and the more it reduces the cost and time. Most typical applications of Taguchi Methods thus far have centered on two main areas:

1. Improving an existing product
2. Improving a process for specific product.
Tremendous additional benefits can be derived from improving the robustness of generic technology (in R&D) so that it is applicable to a family of present and future products and processes. Only a few leading companies worldwide are currently practicing this application, called Robust Technology Development. Farther downstream, Taguchi's methods for what he terms "on-line" quality control (Manufacturing Process Control) can achieve a more cost-effective process control.

Taguchi Methods require a new way of thinking about product development. These methods differ from others in that the methods for dealing with quality problems center on the design stage of product development, and express quality and cost improvement in monetary terms.

The key to competitive leadership is the timely introduction of high quality products at the right price. Achieving maximum efficiency and effectiveness in the research and development process is critical to this effort.

Many people are under the misconception that interactions are not considered in Taguchi Methods; however, the opposite is true. In fact, Dr. Taguchi considers interactions one of the most important issues in his approach. The S/N Ratio is an index for the robustness of quality, and it shows the magnitude of the interaction between "control factors" and "noise factors." Control and noise factors must be assigned to different
groups for the study of robustness, which is significantly different from the traditional DOE approach, where there are no distinctions between control and noise factors. A key difference of Taguchi Methods is the emphasis on measuring the right things for data collection. Instead of measuring symptoms caused by variability of the function, such as defects or failure rate, we measure an energy-related response.

Robust Design is a process for optimization. A technique to help with this is the Signal-to Noise (S/N) Ratio. Signal-to-Noise (S/N) Ratio is the mathematical formula used to calculate the design robustness. The larger the S/N ratio, the more robust the performance. Dr. Taguchi has developed various types of Signal-to-Noise (S/N) ratios as universal indices for the evaluation of quality and reliability of products and processes. The Signal-to-Noise ratio gives a sense of how close the design is to the optimum performance of a product or process. It has been used in the communications industry to compare a line signal (the desired outcome) with the line noises (the undesired outcome). This concept was applied by Dr. Taguchi in the 1950s to other systems, including mechanical, electrical, electro-mechanical, chemical, and many others. "Variability in product/process function is the enemy of quality. Dr. Taguchi relates this deviation from ideal to a concept called Noise. Noise, quite simply, is variability. Moreover, factors that cause variations are referred to as "Noise Factors." By definition, noise factors are uncontrolled either from a
practical or cost standpoint. Quality Loss Function is the standard by which quality-related design factors are studied and weighed. This notion differs from the conventional concept of quality. Instead of defining quality as a positive attribute of a product, it is defined as the financial loss or cost to society caused by undesired variance in the shipped product. It includes costs such as warranty, liability, and lost customer goodwill. The important consequence of this concept is that it brings engineering choices into the realm of economics, something scientists and engineers often find difficult.

The other main result of the Quality Loss Function is that the farther a product's performance varies from the "target" value, the greater the cost, which implies that it is a continuous function. It can serve as a powerful language that permits experts on multidisciplinary product development teams to communicate more easily. This is because all engineering choices are related to a common currency—money. The Quality Loss Function is the most rational tool for making cost-performance trade-off decisions in product and process development, decisions engineers and managers face every day. Finding a correct objective function to optimize in an engineering design problem is very important. Failure to do so can lead to great insufficiencies in experimentation and even wrong conclusions about the optimum levels. Here, we describe some common types of static problems along with their corresponding S/N ratios.
• **Smaller-the-better type problem**

Here, the most desired value for a response or performance index of a product or process is zero. Such problems include minimization of surface defect count in manufacturing computer wafers, minimization of the pollution from a power plant and minimization of leakage current in integrated circuits. Assuming that variable \( y \) denotes the raw performance of a system measured for a particular combination of factor settings in a given experiment (total of \( n \) repeated measurements per experiment), maximization of the smaller the better S/N Ratio is equivalent to minimization of the loss function.

• **Nominal-the-best type problem**

In these types of problems, such as achieving target thickness in polysilicon deposition, the quality characteristics is continuous and non-negative and its target value is nonzero and finite. For these problems, when the mean becomes zero, the variance also becomes zero. Note that maximization of nominal the best S/N ratio uses the mean and variance of responses \( y_i \) where \( i \) is the experiment number ranging from 1 to \( n \).

• **Larger-the-better type problem**

Here, the quality characteristics is continuous and non-negative, and we would like it to be as large as possible. Examples of such
problems are the mechanical strength of a wire per unit cross-section area, the miles driven per gallon of fuel for an automobile carrying a certain amount of load, etc. Maximization of a larger the better S/N ratio type of problem can easily be converted to maximization of a smaller-the-better type problem by considering the reciprocal of the quality characteristics.

Taguchi methods have become increasingly popular in recent years. The documented examples of sizable quality improvements that resulted from implementations of these have added to the curiosity among American manufacturers. In fact, some of the leading manufacturers in this country have begun to use these methods with usually great success. For example AT&T is using these methods in the manufacture of very large scale integrated circuits; also Ford Motor Company has gained significant quality improvements due to these methods. Taguchi robust design methods are set apart from traditional quality control procedures and industrial experimentation in various respects. Of particular importance are:

1. The concept of quality loss functions
2. The use of signal-to-noise (S/N) ratios, and
3. The use of orthogonal arrays.
Taguchi methodology is fundamentally a prototyping method that enables the engineer or designer to identify the optimal settings to produce a robust product, which can survive, manufacturing time after time, piece after piece, in order to provide the functionality required by the customer.

There are perhaps two major features of the advantage of Taguchi methodology. Firstly, it was developed by, and is largely used by engineers rather than statisticians. This removes most of the communication gap and the problems of language traditionally associated with many statistical methodologies. In addition, it means that it is tailored directly to the engineering context. The consequence of this is that the importance of noise variables, which disrupt production, must be considered in addition to the control variables introduced. Optimizing a product corresponds not only to getting its quality characteristics on target but also to minimizing variability away from that target on a piece-to-piece or time-to-time basis.

Taguchi may be used to narrow the spread of the quality characteristic distribution and to identify variables to build control on. SPC may then be used to keep quality characteristics on target by making use of the known spread about the target value. Essentially this is the other novel feature of Taguchi methodology: the use of the so-called Signal-To-Noise ratio to choose the control setting that minimizes the sensitivity to noise. In addition to this the methods are fundamentally evolutionary. One major feature, however, is the codifying by Taguchi of the so-called
Orthogonal Arrays. These are designs for experiments which were largely previously identified by others but are codified by Taguchi in such a way that an engineer automatically has a route to the minimum number of prototypes necessary for experimentation. The numbers are kept deliberately small by sacrificing all the interaction information that may be present in the design (or almost all of it) since information about interactions can subsequently be found in typical industrial applications by evaluating one more prototype - that corresponding to the predicted optimum setting (the confirmatory trial). This is the difference between industrial application and the agricultural context on which most of the Western statistical methods, which foreran Taguchi, were based. In agriculture, responses are slow so that leaving out prototype combinations and sacrificing interactions would necessitate an extra year in the agricultural cycle in order to be able to verify that the predicted prototype combination really was best. In the industrial setting responses are usually fast, so that it is possible to go back immediately and try out one additional prototype. Interactions can, however, be incorporated into Taguchi methodology and he presents a simple graphical codification of these (the linear graphs) to enable the analyst to introduce them systematically and easily. However, only limited numbers can be conveniently introduced without leading to great increase in prototype or experimental sizes.
2.3 Outline Of Thesis

Chapter-1 describes the historical background pertaining to Taguchi and his related work.

Chapter-2 describes the basic ideas, tools and techniques for the use of Taguchi's methods. It also indicates the detailing of the thesis in brief. The evaluation of quality according to Taguchi is based on two major tools: The Signal-to-Noise (S/N) ratio which measures the performance of a quality characteristic in face of noise factor, and the quality loss function (QLF) which measures quality loss due to deviation of a quality characteristic from its target value. Taguchi has found out that a quadratic representation of QLF is an efficient approximation to assess the loss due to poor quality and the ratio of desirable performance (Mean) to undesirable performance (Variance) is referred to as (S/N) ratio. Apart from assessing the loss of a product by QLF one should also see to it that (S/N) ratio be as small as possible, as this would have the product much towards target with less variation. The main concept of this Chapter-3 is to establish relationship between QLF, its three characteristics (Larger is the best, Smaller is the best and Nominal is the best) and S/N ratio i.e. to prove that with the increase of S/N ratio, the corresponding average loss function decreases and with the decrease in (S/N) ratio the corresponding average loss function increases.
The concept of design of experiments and statistical analysis has proved to be an effective tool in formulation and process development. The main advantage in using design of experiments and concept of orthogonal array in the optimization of tablet weight is to identify the potential factors of the experiment. Once the potential factors are identified the tablet weight optimization can be obtained by optimizing the levels of all the critical factors. Chapter-4 presents a systematic approach of optimizing the tablet weight by using the concept of Taguchi's signal to noise ratio in an orthogonal array design. This study confirms the efficiency and effectiveness of using design of experiments and statistical analysis for tablet weight optimization.

Chapter-5 presents a systematic approach of optimizing the defective screws produced during manufacturing by using the concept of taguchi’s signal to noise ratio in an orthogonal array design. This study confirms the efficiency and effectiveness of using design of experiments and statistical analysis for defective screw optimization.

In order to have less number of defective screws during manufacturing process an optimization process was obtained by using the concept of design of experiments and taguchi’s signal to noise ratio. In this chapter a hypothetical example is considered to explain the concept of optimization
of defective screws. Here Signal is referred to the mean of the sample observations & Noise is referred to as variance.

This study confirms the efficiency and effectiveness of using design of experiments and statistical analysis for defective chip optimization.

In order to have less number of defective chips during manufacturing process an optimization process was obtained by using the concept of design of experiments and taguchi's signal to noise ratio. Chapter-6 considers a hypothetical example to explain the concept of optimization of defective chips. Here Signal is referred to the mean of the sample observations & noise is referred to as variance.

Chapter-7 presents a systematic approach of optimizing the factor levels of an orthogonal array & reduction of estimated variance for error by using the concept of taguchi's signal to noise ratio.

In this chapter we have considered a hypothetical example to explain the concept of optimization of factor levels of an orthogonal design. Here Signal is referred to as the mean of the sample observations & noise is referred to as variance.

The first concept underlines the basic difference between Taguchi methods and the SPC methodology. Whereas SPC methods emphasize the attainment of an attribute within a tolerance range and are used to
check product/process quality, Taguchi methods emphasize the attainment of the specified target value and the elimination of variation. In Chapter-8 an attempt is made to establish the relationship between Taguchi's Loss function and $X$ control chart.

Chapter-9 presents a systematic approach of optimizing the tablet hardness by using the concept of taguchi's S/N ratio in an orthogonal array design. This study confirms the efficiency and effectiveness of using design of experiments and other statistical tools for tablet hardness optimization. In order to have less number of tablets with tablet hardness lower than its target value during the manufacturing process an optimization process was obtained by using the concept of design of experiments and taguchi's signal to noise ratio. In this chapter the concept of tablet hardness optimization has been explained by considering a practical application.

In Chapter-10 an attempt is made to explain the application of Taguchi's concept to P-B (Plackett Burman) screening design with a hypothetical example. The objective of the experiment is to find out potential factors that are affecting the characteristics of the tablet (say) dissolution of tablet.
Chapter-11 discusses the problem that will help us in finding optimal settings of an experiment by application of Taguchi techniques for smaller the better type of quality characteristic. The improvement of a product is verified by computing the loss of obtained optimal settings & that of initial settings of a product.