4. A Primer on the Taguchi System of Quality Engineering

by Vedaraman Sriraman

Quality assurance (QA), as practiced today, was developed largely in the 20th century. The basic tools of this approach, which is also referred to as conventional quality assurance, are inspection and statistical process control (SPC). Initially, inspection was used to cull nonconforming parts and either rework or scrap such parts. In the 1920s, Walter Shewhart introduced the control chart concept that lent the quality assurance processes a scientific basis. Following the control chart, Dodge, Romig, and Juran introduced sampling plans for inspection. These were based on statistical foundations. Quality assurance as practiced today uses sampling-based inspection to keep production processes under statistical control.

This was the QA approach that American quality gurus like Deming and Juran preached to the Japanese in the 1950s. At that time, Japanese products did not enjoy the reputation they do today. In fact, to a large extent, "made in Japan" meant junk. The realities of an island economy and war losses, however, pressured the Japanese to seek new and novel ways to boost productivity and quality. Therefore, in spite of the indifferent response that Deming received in the United States, he had a very captivated audience in Japan. The adoption of these quality procedures led to Japan's emergence in the 1970s as a formidable global competitor.

Since then, Japan has been innovating and furthering these fundamental quality assurance concepts. The result has been the development of such concepts and methodologies as the Taguchi System of Quality Engineering and Total Quality Management (TQM). The aforementioned developments have enabled Japan to stay globally competitive in the 1980s and 1990s, despite the ever-decreasing product development times and the requirement of lean-agile manufacturing systems. It is believed that Taguchi's concept of robust designs is one of the reasons for the great success of Japanese automobiles and electronic products. Today Japanese quality gurus like Ishikawa and Taguchi are touring the United States and delivering their messages.

Technology educators should incorporate this important concept in a senior-level or graduate-level QA class to prepare tomorrow's technologists better. This particularly applies to teachers who instruct students in industrial technology/technology education programs.

TRADITIONAL QUALITY ASSURANCE - SPC

Traditional quality assurance has a strong basis in statistical theory. The objective here is to analyze data for statistical signals that enable systematic process improvement. In contrast to inspection-based quality assurance, which merely weeds out poor quality products, SPC helps achieve a *defect prevention system.*

The scientific basis for the control chart, which is the main SPC tool, is based on the properties of normal distribution and is illustrated in Figure 1. This distribution, which is characteristic of all random processes, contains 99.7% of any population within a distance of three times the standard deviation (σ) from the mean ($\bar{x}$) on either side. Thus a manufacturing process under the sole influence of random effects will have just 0.3% or 3 out of 1000 parts outside the 3σ limits from the mean. In using a control chart, the user draws random samples from a process and calculates the mean for each sample. Then the grand mean $\bar{\bar{x}}$ and 3σ on either side of the $\bar{x}$ are drawn on a chart as shown in Figure 2. Next the individual sample means are plotted on the chart and, if all these values lie within the 3σ limits on either side of $\bar{x}$, then the process is under random influences only. If some points lie outside these limits or show certain specific patterns, then these are signals that nonrandom causes, such as a broken cutting tool, change of a work shift, or change in material, etc., is at work. Through the use of these signals, control charts indicate when a process is to be diagnosed and corrected so that defective products can be prevented in the future.

Although SPC is a much better quality assurance option than a mere inspection, there is some concern regarding a quality assurance program that is only SPC based. First, it is felt that charting is least applicable to low volume, short-run production (Harmon, 1990). Today, global competition and a consumer-driven market have necessitated that design changes occur frequently. This means that for many manufacturing plants, production characteristics have changed from high volume, long-run production to low volume, short-run production. Control charts work best for high volume products that run almost continuously.

Second, SPC is expensive to implement and maintain. As a consequence, the Toyota Motor Corp. uses almost no SPC (Ealey, 1988). Third, SPC does not improve the product's design quality (Ealey, 1988), but merely helps to keep a process under control and maintains previously designed quality levels. SPC indicates when a process is out of control during the manufacturing stage. Correcting quality problems at this stage is expensive, as Figure 3 shows, because a factor of 10 rule is applicable. Basically, this rule states that it costs 100 times more to rectify a problem at the manufacturing stage than it would at the product design state. The Japanese seem to have paid due attention to this rule and have built quality into their products during the design stage. Thus the Japanese regard SPC as a first step (Ealey, 1988).

The next steps that the Japanese use are the Taguchi methods. These methods of designing quality into products are touted as being responsible for the high quality of Japanese products. The following section presents the Taguchi methods.

THE TAGUCHI SYSTEM OF QUALITY ENGINEERING

In contrast to traditional quality assurance, which focuses on on-line quality assurance, the Taguchi system focuses on designing quality into products and processes (i.e., off-line quality control). Quality concerns are addressed at the drafting board as opposed to

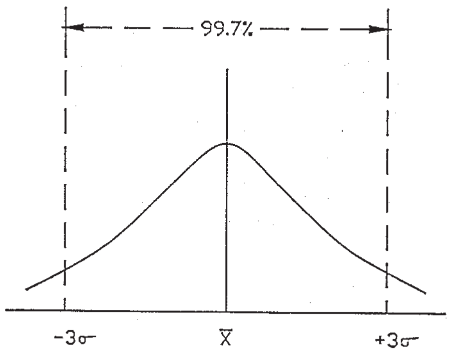

Figure 1. **Normal Distribution**

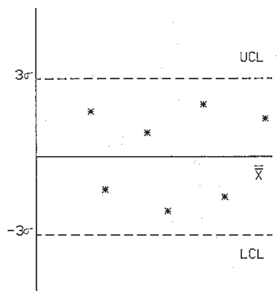

Figure 2. **Control Chart**

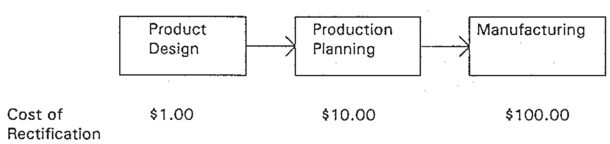

Figure 3. **Factor of Ten Rule**

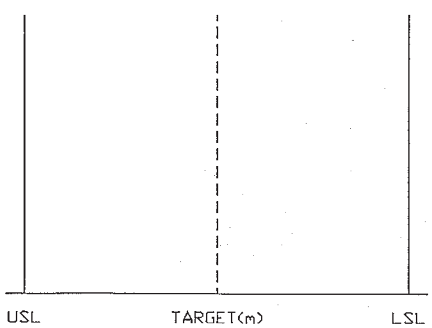

Figure 4. **Goal Post Syndrome**

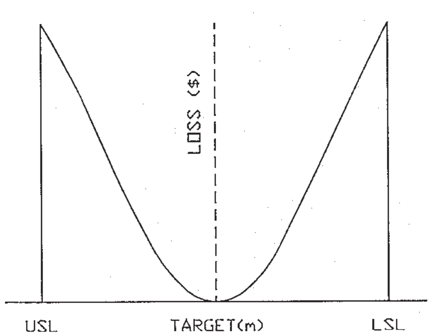

Figure 5. **Loss Function**

addressing them on the shop floor. This approach emphasizes the engineering side of quality issues rather than the managerial side. At the very heart of this method is the use of statistically designed engineering experiments. These help identify product and process parameter settings that provide for least variation in product characteristics. Specifically, the Taguchi system is based on the following three important precepts.

Quality Definition. Quality has been traditionally defined as "conformance to specifications" or "fitness for use." These quality definitions focus only on tangible losses, such as those associated with lack of conformance and the consequent scrap and rework costs. Taguchi's definition of quality is based on a more comprehensive view of the production system. He defines quality as "the loss a product imposes on society after it is shipped" (Ealey, 1988). This view of quality not only considers such tangible losses as manufacturer's cost due to warranty-related problems, but also hidden losses due to consumer inconvenience associated with a poor quality product and loss of consumer trust and of market shares.

Quality Loss Function. Conformance to specifications leads to what has been referred to as a "goal-post syndrome." As shown in Figure 4, the upper specification limit (USL) and lower specification limit (LSL) define the extents of the goal. A product is considered good as long as it lies between the two goal posts. There is a wide variability however, between a product that lies close to either goal post and one that lies close to the mean. Based on mathematical analysis, Taguchi has proposed a *quadratic loss function,* which states that any deviation of a product characteristic from the mean or target value entails a loss and that this loss is proportional to the square of the deviation. The function, which is graphed in Figure 5 is as follows:

$L(\$) = k(y-m)^2$

where $L(\$)$ = loss in dollars

k = a constant

y = product characteristic

m = target value

The loss function, therefore, focuses the manufacturer's attention on reducing product variability as opposed to merely urging conformance to specifications. An interesting real life example clearly illustrates the loss function vs. conformance to specification concepts. Several years ago, the Ford Motor company, which owns about 25% of Mazda Motor corporation, had asked the Japanese company to make some transmissions for a car that Ford was selling in the United States. The rest of the transmissions were made at Ford's plant in Batavia, Ohio. Both companies used the same product specifications. After a certain volume of automobiles had been sold, it was found that Ford-built transmissions were costing more in terms of warranty and were also getting more customer complaints about noise. Therefore, Ford disassembled a certain number of automobiles from both facilities and measured samples of transmissions. While gauging transmissions from Mazda, little or no variations were registered, causing Ford to wonder if the gauges were malfunctioning. A closer investigation revealed that Ford's manufacturing was based on the conformance to specification approach, while that of Mazda was based on continuously reducing variability around the target value. Thus for identical target values, Mazda was using only 27% of the allowed tolerance range, while Ford was using 70% (Ealey, 1988).

Parameter Design. Product variation is caused by a great many factors. These factors may be divided into two major categories: external and internal factors. External factors are usually due to the effects of temperature, humidity, pressure, vibration, etc. Internal factors are product parameter settings, such as the alloy composition of a steel or the values of resistors and capacitors in an electrical circuit. External factors, which are also sometimes called *noise* factors, are either impossible or very costly to control. Internal factors are controllable and may be judiciously selected during the product design stage. A frequently cited example in this connection is a confectionery business that was making caramel candy. The business's concern was to reduce product variability, that is, prevent candy from melting in places such as Phoenix, Arizona, as well as prevent it from cracking in places such as Casper, Wyoming. The external factors in this case are environmental temperature and humidity, which are impossible to control. The company set the level of caramel and cocoa, which are internal facets in its recipe, at levels that produce least variability. Thus, parameter design focused on identifying internal factors and their setting (or levels) that would render the product insensitive to deteriorating external influences. Such designs are called *robust designs*. Since parameter design is done at the design stage, it reduces the need for extensive in-process inspection and quality control. Thus, parameter design helps achieve quality engineering as opposed to quality control.

SUMMARY

From the days of inspection-based quality control, quality assurance has come a long way today. Dr. Taguchi's quality engineering methodology has received very wide attention in the last five years, which is evidenced in the number of courses offered by several universities and organizations such as the American Supplier Institute (ASI), American Society for Quality Control (ASQC), American Society of Mechanical Engineers (ASME), Institute of Industrial Engineers (IIE), and the Society of Manufacturing Engineers (SME). The Taguchi approach to quality focuses on designing quality into products at the design stage. By addressing quality issues at the design stage, this methodology reduces development lead times and quality costs.

References

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Dr. Sriraman is an Assistant Professor in the Department of Technology at Southwest Texas State University, San Marcos. He is a member of Alpha Mu Chapter of Epsilon Pi Tau.