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An overview on Taguchi's method employed for product quality improvement and its control

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Abstract: Genich Taguchi, a Japanese engineer and statistician, developed a methodology for improving and controlling the quality of produced goods. His robust optimization technique is widely used in the field of quality improvement and experimental design. Taguchi's approach aims to improve the quality of products and processes by minimizing variation and reducing the sensitivity of a system to various factors. The statistical approach for quality is valid for the various areas of engineering such as product design and development, life-sciences, and management fields (basically advertising and marketing). Taguchi's statistical approach is incorporated by the various techniques of the "concept of loss function" and "offline quality control". He offered a special mathematical relationship between performance and expected harm (Loss), this is explained by the "concept of the loss function". Taguchi's method has been widely applied in various industries, including manufacturing, engineering, and design, to optimize processes, reduce variation, and enhance product quality. It provides a systematic and efficient approach to experimentation and optimization, helping organizations achieve higher levels of quality and performance while minimizing costs.

Keywords: Quality, concept of loss function, Product design, system design

1. Introduction:

The term "quality" gained prominence after World War II. During this period, manufacturing organizations began to adopt philosophies focused on improving product quality. By the mid-twentieth century, the quality of products and services became a key concern. Dr. Genichi Taguchi, a Japanese statistician, played a significant role in this shift by integrating statistical theories into quality improvement practices. After World War II, many European nations perceived Japanese technology as subpar, particularly in the realm of communication services. In response, Taguchi, who was in charge of the R&D section of the Electrical Communication Laboratories (ECL) in Japan, set out to enhance product quality. He observed that engineering experimentation and testing consumed substantial time and resources. He argued that insufficient emphasis was placed on creative brainstorming, which could help minimize resource expenditure [1].

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Taguchi introduced the concept of quality production, emphasizing the importance of quality control and inspection on the production floor. Before his contributions, the idea of quality production was not widely recognized. His work laid the groundwork for Total Quality Control (TQC), a comprehensive system that encompasses Quality Development, Quality Maintenance, and Quality Enhancement. TQC focuses on improving various subsystems within an organization to enable cost-effective marketing, engineering, production, and service delivery. This approach ultimately leads to greater customer satisfaction. Taguchi's methods became vital for developing sound engineering designs and efficient manufacturing processes. They also foster viable service activities necessary for delivering high-quality products. In addition to Taguchi, other pioneers like Joseph Juran and W. Edwards Deming contributed to the field of quality management [2]. Their collective efforts underscored the importance of continuous improvement and systematic approaches to quality. Implementing a quality program requires careful planning. Organizations should often start by selecting one or two areas for improvement. Achieving tangible results in these areas can build momentum for further changes. Gradually expanding quality initiatives across other sectors of the organization can lead to more comprehensive improvements. Additionally, training employees in quality principles is essential. This helps create a culture that values quality at every level. Management commitment is also crucial for sustaining these efforts over the long term. Regular assessments and feedback loops can further enhance quality initiatives [3].

2. Concepts of Taguchi for Quality Improvement:

Taguchi's approach to quality improvement involves several key concepts and principles. Here are some of the fundamental concepts associated with Taguchi's method:

2.1 The Concept of the Loss Function:

Dr. Taguchi has coined a theory of total loss function [4]. He defines quality as "the total loss imparted to the society from the time a product is shipped to the customer". The loss is calculated in monetary terms and includes all costs over a near-perfect product cost. Dr. Taguchi has established a mathematical relationship between actual product performance and expected loss to society. The formula for the Taguchi Loss Function is as follows:

$$\textbf{Loss (L)} = k*(Y - T)^2 \quad \textbf{(1)}$$

Where

- L represents the loss due to deviation from the target.
- k is a constant representing the cost of poor quality.
- Y is the actual or observed value of a product or process parameter.
- T is the target value or desired performance level.

The loss function is quadratic, meaning that as the deviation from the target (Y - T) increases, the loss grows exponentially.

The loss function (L) eq. (1) is expressed further as:

$$\textbf{L } (y) = k \cdot \textbf{(Deviation from target)}^2 \quad \textbf{(2)}$$

The deviation from the target (Y-T) is squared to give more weight to larger deviations. The goal of Taguchi's method is to minimize the loss function, which means minimizing the squared

deviations from the target. By doing so, Taguchi aimed to design products and processes that are robust and less sensitive to variations, ensuring that even slight deviations from the target have a minimal impact on the quality and performance of the product [5].

Taguchi's definition can be expanded to the development and manufacturing phases of the product. An ill-designed starts making losses to society right from its inception and continues to do so till it is improved [6]. There are two major categories of losses to society in terms of product quality.

i. One relates to the harmful effects it causes to society after consumption of poor-quality products and the ill effects it leaves on the environment concerning pollution etc.
ii. Another relates to expenses incurred in the rejection and reworking of the product to bring it to acceptable quality standards so that it does not cause any more apparent harm to society.
iii. The other idea deals with the actual method of attaining the quality of a product is determined by how closely its design parameters align with the target value, rather than simply meeting predetermined specifications at one end of an acceptance range yet may be having shorter shelf life.
iv. Another idea calls for measuring deviations from a given design parameters in terms of the overall life cycle cost of the sample; this cost will include the cost of wastage product, re-engineering, inspection, returns, warranty, after-sales service, and product replacement. Dr Taguchi says quality improvement is never never-ending process, he said enterprises should continually strive to reduce variations between the actual quality and the target value.

2.2 Off-Line Quality Control:

Dr. Taguchi advocated for a proactive approach to quality improvement, starting from the design phase and continuing through production. He introduced an offline strategy, focusing on prevention rather than inspection, to ensure quality is built from the outset. Taguchi's philosophy emphasizes designing products to be robust and resilient, unaffected by external factors in the manufacturing process [7]. In essence, he believed that quality is a deliberate design element, not something that can be inspected or added later.

3. Stages of Quality Improvement in Product Design:

To achieve desirable product quality by design, Dr Taguchi has proposed a three-stage process:

3.1 System design: The system design phase focuses on establishing optimal working levels for design factors. Engineers utilize their judgment to select appropriate raw materials, equipment parts, and nominal product process parameters based on current technology. This phase also emphasizes the integration of new concepts and innovations from related fields of science and technology, ensuring that the design is both effective and forward-thinking. By balancing these elements, engineers aim to create efficient and functional systems that meet desired specifications while leveraging advancements in technology. [8].

3.2 Parameter Design: Parameter design identifies the optimal factor levels that enhance the performance of the product and process being studied. This approach aims to select the best conditions to ensure that countless variables do not negatively impact system

performance. By focusing on these optimal settings, organizations can achieve more consistent and reliable outcomes, minimizing the influence of external factors on the system's effectiveness [9].

3.3 Tolerance Design: Tolerance design is used to fine-tune the result of parameters designed by tightening the tolerance of factors that significantly influence the product. Tolerance design will focus on identifying the need for better raw materials, advanced equipment better processes, and scaring funds for control activities [10].

4. Taguchi's Methodology:

i. Dr. Taguchi's approach is based on established optimization principles and experimental design. His quality philosophy and experimental methodology are applied in a four-step process, which enables the systematic improvement of product design and performance [11]. By following these steps, designers and engineers can identify optimal conditions and settings to achieve superior quality and reliability. This process includes brainstorming quality characteristics and design parameters critical to both the product and the process.
ii. Design and perform the experiments.
iii. Simulate the results to determine the best conditions.
iv. Run a conformance test using optimum conditions.

5. Comparison Between Taguchi's and Six Sigma Methods:

Aspect	Taguchi's Method	Six Sigma Method
Overview	Focuses on robust design and minimizing variation in process through experimental design.	Aim to improve process quality by identifying and eliminating defects using Statistical Methods.
Objective	Enhance quality and performance through design optimization.	Reduce defects and improve process consistency.
Approach	Utilizes experimental design, particularly Orthogonal Arrays.	Employs DMAIC (Define, Measure, Analyze, Improve, Control) framework.
Statistical Tools	Relies on Taguchi loss function and robust design principles.	Uses a variety of statistical tools, including control charts, hypothesis testing, and regression analysis.
Focus	Emphasizes design phase and pre-production quality.	Focuses on process improvement and defect reduction throughout the production cycle.
Application	Best suited for product design and development.	Applicable across various industries for process improvement.
Advantages	Reduces development time and cost, improves product quality early in the design phase, and focuses on minimizing variability.	Systematic approach to process improvement, Data-driven decision-making, and Strong focus on customer satisfaction.

6. Concluding Remarks:

In summary, Taguchi's method offers a systematic and efficient framework for quality improvement, and its principles continue to influence the field of experimental design and optimization [12]. Organizations that adopt Taguchi's approach benefit from reduced variation, increased robustness, and ultimately, improved product quality and customer satisfaction. In brief, the following conclusion is drawn:

1. Dr. Taguchi's use of the "total loss function" has compelled cost accountants and process engineers to carefully reevaluate their previous methods [13].
2. Dr Taguchi spells quality as the total loss effective to the society from the time; a product is shipped to the customs [14]. All costs incurred over the price of a suitable product are included in the loss, which is expressed in monetary terms. Therefore, when product quality is concerned, the product should be evaluated from the very beginning, all the way through the production process, the final product, and society's consumption of it [15].
3. His emphasis is more on quality control, which is an ongoing continual, and never-ending process, He believes in the philosophy that every product how so ever good in quality, still needs improvisation because expectations and the needs of society always keep encouraging [16].
4. Dr Taguchi has also emphasized that quality control is simultaneously required in both the product as well the process.

In conclusion, Taguchi's method for quality improvement is a robust and systematic approach that has been widely applied in various industries. The key principles and concepts associated with Taguchi's method contribute to the optimization of processes and products, leading to enhanced quality, reliability, and performance. The evolution of quality management since World War II has transformed how organizations approach product and service quality. By adopting methodologies like TQC and learning from pioneers like Taguchi, Juran, and Deming, companies can significantly improve their quality outcomes. As the landscape of manufacturing and services continues to evolve, a strong focus on quality remains imperative for success.

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