JOURNAL OF BAKU ENGINEERING UNIVERSITY- MECHANICAL AND INDUSTRIAL ENGINEERING
2025. Volume 9, Number 1 Pages 51-56

UOT: 539
DOI: https://doi.org/10.30546/09085.2025.01.008

APPLICATION OF THE TAGUCHI METHOD IN PROCESSING EXPERIMENTAL RESULTS

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ARTICLE INFO

Article history:
Received: 2025-02-20
Received in revised form: 2025-03-03
Accepted: 2025-04-22
Available online

Keywords:
Taguchi method; experimental results; process optimization; Signal-to-Noise ratio; orthogonal arrays; statistical analysis.

JEL Classification: C15, C61, L60

ABSTRACT

This study examines in detail the application potential of the Taguchi method in processing and optimizing experimental data. The Taguchi method is an effective technique developed to improve manufacturing processes and especially to optimize the effects of controllable parameters, which is widely used in the field of quality engineering. In the study, the optimization of the main parameters that are effective in minimizing surface roughness (Ra) during a material processing process in a manufacturing process is considered as a case study, and how maximum efficiency can be achieved with less experimentation is demonstrated with solutions. As a result, the generalizability of the method in engineering applications and the potential benefits it can offer in different industrial areas are discussed. In addition, in the processing of the results of the experiment, the practical results of the Taquchi method have been processed.

1. Introduction

Experimental designs play an important role in improving quality in production and operational processes, increasing efficiency to high levels and achieving the best results with minimum cost. Traditional experimental design methods generally require a large number of experiments, resulting in high costs in terms of time and resources. In contrast, the Taguchi method allows parameter optimization with a small number of experiments. This method is an effective approach widely used in the field of quality engineering and experimental design.

Studies in the literature on the Taguchi method show the effectiveness of the method in different industrial applications. For example, Ross has shown that the Taguchi method provides a significant cost advantage in quality improvement projects in the automotive sector [1]. Phadke, on the other hand, has emphasized the simple and systematic structure of the method in design optimization and emphasized how valuable the results obtained with a small number of experiments are in the decision-making process [2]. Similarly, Güllü et al. have shown that the Taguchi method is an effective method in optimizing surface roughness in applications in the steel industry [3]. In [6] and [7], experimental values of wear on shafts subjected to longitudinal bending deformation and shafts with different widths were analyzed using the Taguchi method. The optimal combination of controlled factors for obtaining the smallest wear was determined. The percentage of factors that most affect wear is shown.

The aim of this study is to present the theoretical background of the Taguchi method and an application example to reveal the advantages and application potential of the method.

2. Theoretical Foundation of the Taguchi Method

The Taguchi method, developed by Genichi Taguchi, focuses on robust design to enhance product and process performance by reducing the influence of noise factors. The Taguchi method involves several key concepts that allow for effective experimentation and data analysis. The main components include:

- Factorial Design: This involves selecting a set of factors that may affect a given process and evaluating their interactions. Taguchi typically uses a fractional factorial design to reduce the number of experimental runs.
- Orthogonal Arrays (OAs): These arrays are pre-arranged matrices that allow for the efficient and balanced study of the effects of multiple factors on an experiment. By using OAs, the number of experiments can be minimized, ensuring an optimal combination of factors.
- Signal-to-Noise (S/N) Ratio: The S/N ratio is a crucial metric in the Taguchi method. It quantifies the variability in an experiment, where the "signal" represents the desired output and the "noise" signifies the variability or unwanted influences. Maximizing the S/N ratio leads to improved robustness by minimizing the effects of noise factors.
- Control Factors and Noise Factors: In the Taguchi method, control factors are variables that the experimenter can manipulate, while noise factors represent uncontrollable elements that may affect the outcome. The goal is to identify settings for the control factors that minimize the influence of noise.

Benefits of the Taguchi Method

- Efficiency: Reduces the number of experiments without compromising reliability.
- Simplicity: Straightforward implementation using predefined orthogonal arrays.
- Robustness: Focuses on minimizing variability and achieving consistent performance.
- Cost-effectiveness: Lowers experimental costs and resource requirements.

3. Taguchi Method in Experimental Design

The Taguchi method is an experimental design method used in quality control and product development processes. This method aims to conduct a minimum number of experiments to optimize the performance of a particular process or product. The application steps of the Taguchi method can be summarized as follows:

1. Problem Definition: Targeted quality characteristics and parameters to be improved are determined. The output of the problem (e.g. maximum yield, minimum error) is defined.

2. Determination of Controllable and Uncontrollable Factors: Controllable factors: Process or product parameters (e.g. temperature, speed, pressure). Uncontrollable factors: Environmental effects or external conditions (e.g. humidity, vibration).

3. Determination of Experiment Levels and Factors: Appropriate levels are selected for each controllable factor (e.g. low, medium, high). Levels are important for determining the variety of experiments.

4. Selection of Orthogonal Array: The Taguchi method uses orthogonal arrays in planning experiments. These arrays provide a balanced distribution between factors and levels. A suitable orthogonal array is selected to reduce the number of experiments (e.g. L4, L8, L16).

5. Conducting Experiments: Experiments are performed in accordance with the plan prepared according to the orthogonal array. Process or product performance is measured under each condition.

6. Calculating Signal-to-Noise (S/N) Ratio: S/N ratio is used to evaluate performance variability. The S/N ratio formula is selected according to the targeted quality characteristic:

o Smaller is better: Minimum error is desired.

o Larger is better: Maximum performance is desired.

o Nominal is better: Closeness to a specific target value is desired.

7. Analysis and Optimization: Based on the experimental results, the effects of factors and levels are analyzed. The combination of factors and levels that provides the best performance is determined.

8. Verification Experiment: A verification experiment is performed using the optimized parameters. The obtained results are compared with the predicted results.

9. Interpretation and Application of Results: The effect of the optimum parameter combination on the process or product is evaluated. If necessary, the method is integrated into practical applications.

4. Practical Applications of the Taguchi Method

The Taguchi method has been applied in a wide variety of fields, with notable success in manufacturing, materials processing, and quality control. Some of the key applications include:

- Manufacturing and Process Control: In manufacturing, the Taguchi method helps identify optimal settings for machine parameters, tooling, and operational procedures to reduce defects and improve product consistency. It is commonly used for process optimization in the automotive, electronics, and aerospace industries.
- Quality Improvement: The Taguchi method is instrumental in achieving consistent product quality by identifying factors that contribute to variability and providing solutions to minimize their impact. It has been used in the production of consumer goods, pharmaceuticals, and other sectors where quality is paramount.
- Materials Science: In materials processing, the Taguchi method has been used to optimize the properties of materials such as metals, polymers, and composites. By systematically studying factors such as temperature, pressure, and time, researchers can fine-tune processing parameters to achieve desired material characteristics.

Sample work. Problem: In a production process, it is desired to minimize the surface roughness (Ra) during a material processing operation. Cutting speed, feed rate and depth of cut are determined as process parameters. Taguchi method will be used to analyze the effect of these three factors on surface roughness and to find the most suitable parameter combination.

1. 1. Factors and Levels:

1.1. Cutting Speed (m/min):

o Level 1: 100

o Level 2: 150

o Level 3: 200

1.2. Feed Rate (mm/min):

o Level 1: 0.1

o Level 2: 0.2

o Level 3: 0.3

1.3. Depth of Cut (mm):

o Level 1: 0.5

o Level 2: 1

o Level 3: 1.5

2. Experimental Design: Taguchi method uses orthogonal arrays to minimize the number of experiments. Since there are three factors and three levels in each, L9 array was deemed appropriate. A total of 9 experiments will be conducted in this array.

Table 1. Level values of the factors managed

Experiment No.	Cutting Speed	Feed Rate	Depth of Cut
1	50	0.1	0.5
2	50	0.2	1.0
3	50	0.3	1.5
4	100	0.1	1.0
5	100	0.2	1.5
6	100	0.3	0.5
7	150	0.1	1.5
8	150	0.2	0.5
9	150	0.3	1.0

3. Experimental Results: Surface roughness (Ra, in micrometers) will be used to evaluate the machined quality of the metal surface. Surface roughness (Ra) was measured for each combination and the results were recorded:

Table 2. Measured value of the surface culture

Experiment No.	Cutting Speed	Feed Rate	Depth of Cut	Ra (μm)
1	50	0.1	0.5	1.2
2	50	0.2	1.0	1.5
3	50	0.3	1.5	2.1
4	100	0.1	1.0	1.0
5	100	0.2	1.5	1.4
6	100	0.3	0.5	1.8
7	150	0.1	1.5	0.9
8	150	0.2	0.5	1.3
9	150	0.3	1.0	1.7

3. 2. Analysis of Data: Based on the analysis of the surface roughness values obtained at the end of each experiment, it can be determined which factors and levels provide the lowest roughness (i.e. the highest quality).

Calculation of Signal/Noise Ratio (S/N Ratio): Taguchi method tries to optimize the signal/noise ratio. As a measure of surface roughness, smaller-the-better approach is usually used. In this case, lower roughness is better. Since the surface roughness is to be minimized, the "Smaller-the-Better" criterion is used. The S/N ratio is calculated as follows:

$$^{S}/_{N} = -10 \cdot log_{10}\left(\frac{1}{n}\sum_{i=1}^{n} y_i^2\right) \qquad (1)$$

Interpretation of Results: The effects of factors on surface roughness are calculated. Average S/N ratios are found for each factor and graphs are drawn. It will reveal which factors and levels show better performance.

Result: For example, as a result of the analysis, the following finding can be obtained:

- Cutting speed = 150 m/min
- Feed rate = 0.1 mm/min
- Cutting Depth = 0.5mm

This combination results in the lowest surface roughness (highest quality).

6. Validation Experiment: Experiment is performed with the obtained optimum parameters and the results are compared with the predicted improvement.

This example shows an application and analysis of the Taguchi method, which allows you to quickly assess the effects of factors and determine the conditions that will provide the best performance.

Conclusion and discussions

This study has shown that the Taguchi method is an effective tool for parameter optimization with a small number of experiments. The simple and effective structure of the method has a wide application potential in the field of engineering and quality control. Future studies can contribute to the method becoming more generalizable by examining its applications in different industrial areas.

The Taguchi method provides a powerful and systematic framework for processing experimental results. The Taguchi method, through the use of orthogonal arrays and S/N ratios, helps identify optimal operating conditions for processes and products efficiently while minimizing the number of trials required. The method's application spans numerous industries, offering valuable insights into process improvement, quality control, and product design. As industries continue to demand higher levels of precision and efficiency, the Taguchi method remains a valuable tool for achieving these objectives.In future applications, the integration of modern statistical software and machine learning techniques could further enhance the power of the Taguchi method, enabling even more precise optimization in complex systems.

The theoretical foundations of the Taguchi method are developed here, and the application areas are shown. In addition, the application sequence of the Taguchi method is developed in the development of the experimental results.

An example of the application of the Taguchi method is shown here. Here, the effect of cutting depth, cutting speed and feed rate on the surface roughness was analyzed using the Taguchi method. As a result of the analysis, the optimal values of cutting depth, cutting speed and feed rate were determined. With these values, the minimum value of surface roughness is obtained.

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