Data Analysis for Stabilizing Product Quality and the Mahalanobis Taguchi (MT) Method

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Recently in the manufacturing industry, there is a strong need to stabilize product quality while responding to diverse market needs. Plant operation should respond flexibly to external changes and requirements such as variations in raw materials quality and rigorous quality requirements from customers. However, it is difficult to satisfy quality only with final inspection processes; new approaches are needed to improve operating management by determining target quality values to be controlled in each process or at each production unit.

Under these circumstances, Yokogawa has been proposing solutions for stabilizing the quality of products in various process units of customers such as quality management, manufacturing, and production engineering. This paper introduces a solution for quality stabilization that uses the Mahalanobis Taguchi (MT) method as a core data analysis technique.

INTRODUCTION

Lower cost competitiveness due to the rise of emerging countries and lower productivity due to the diverse needs force the Japanese manufacturing industry to increase its global competitiveness on a daily basis. To do so, the production department must always improve the quality, lower the cost, and meet the delivery time.

Despite no significant changes in the production processes in themselves, it is difficult to keep the product quality stable. This is because factors such as variations in the quality of the raw materials input into the production processes and aging of the manufacturing facility cause deterioration in product quality at the production sites. Despite those circumstances, high quality is required for the products to be shipped.

This paper first describes an ideal production process to ensure better process quality then organizes challenges for stabilizing the product quality and keeping the quality stable, and finally presents Yokogawa’s solutions to those challenges.

CONTINUOUS IMPROVEMENT OF PRODUCTION PROCESS

The following describes an ideal production process that can best manage the quality and then describes the importance of the process quality ensured by the production process.

Production Process Improvement

A production process is a process that not only meets the product specifications (including those of the functions) but also ensures the product quality using the four Ms (Material, Machine, Method, and Man). As shown in Figure 1, conventional production emphasizing inspection checks the product quality at the final inspection before the products are shipped, so the probability of generating a loss increases and the production efficiency decreases. To increase product competitiveness, the speed of production improvement to be performed to increase the product quality, reduce the delivery time, and lower the product cost must be increased. To do so, we believe that improvement is required to create production to ensure the process quality. This can be accomplished by establishing an environment for production ensuring the process quality, where quality inspection is performed in each process to ensure the in-process quality (1).

Ensuring Process Quality

To ensure the quality in each process, the concept of the quality control method, process and production systems, etc. must be reviewed as a whole. As a result, the quality, cost, and delivery (QCD) can be improved by reconstructing the entire production process.

To ensure the product quality, analysis is required to identify what kind of quality is ensured in which process and what control parameters are used for that purpose. The immediate goal of ensuring the process quality is to increase the product quality, but the ultimate goal is to increase the product competitiveness. In other words, the goal is to increase the quality level by ensuring the process quality to boost the sales and profits.

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CHALLENGES FOR STABILIZING QUALITY

Despite the production process improvement and establishment of a production environment where each department performs in-process inspection as described above, there are still various challenges for the production process. The following organizes the challenges that are directly related to the quality.

False Detection of Quality
There are two types of error in the quality inspection process. The first type of error is to determine a product conforming to the quality standards as a nonconforming product. The second type of error is to determine a nonconforming product as conforming. A high false detection rate in this way generates waste in the final inspection process.

Repeatedly Occurring Asset Failures
In theory, early detection of asset failure signs enables taking measures to avoid the failure, but in reality, data analysis cannot identify indicators or cause data to find failure signs. Therefore, measures to prevent asset failures from occurring are not taken and asset failures occur repeatedly.

Burdensome Root Cause Analysis for Quality Abnormalities
It is difficult to assign an analyst for analyzing the mechanism of abnormalities and variations or accumulate the analysis know-how, and abnormality causes are intricately related to each other. Therefore, it takes a lot of time to analyze the cause when an abnormality occurs.

Indefinite Optimal Production Conditions
The optimal critical process parameters to ensure the desired product quality in each process cannot be determined because of variations in the raw materials and the demanding quality requirements for the products to be shipped.

QUALITY STABILIZATION SOLUTIONS

The importance of quality control techniques continues to increase because the product quality is ensured in the production process and the quality must be kept and controlled at a high level.

Yokogawa’s quality stabilization solutions shown in Figure 2 provide each department with appropriate solutions to the challenges described above to stabilize the quality in plants.

First, the product quality is accurately determined as conforming or nonconforming to establish the foundation for quality management. Then, abnormality and failure signs of the operation and asset are detected to reduce the defective products to a minimum. Furthermore, abnormality and failure root cause analysis is performed to reduce the variations in the quality, and then the optimum critical process parameters are redesigned to ensure that the product achieves values as close to the desired physical property values as possible. Finally, real-time monitoring is performed to ensure that the optimum product quality control values are maintained at all times. The following shows the details.

Quality Abnormality Determination Solution
This solution is intended for the quality management department that improves the pre-shipment product quality inspection to prevent false product quality pass/fail determination and reduce customer complaints to zero. First, a Laboratory Information Management System (LIMS) is introduced to automatically collect the in-process quality inspection results in order to prevent operation errors, reduce inspection manpower, and prevent inspection data tampering. Then, variations in the quality data are visualized with high accuracy to prevent nonconforming products from being passed to the next process.
Abnormality Sign Detection Solution
This is a solution intended for the operation management and asset maintenance departments. It detects process and asset data abnormality signs and can issue an alarm earlier than the conventional threshold alarm system that uses normally collected data such as temperature, flow rate, and pressure data. This solution can minimize defective products. Asset failure prediction analyzes mainly the asset data with a special focus on the asset failures that are directly related to the quality abnormalities.

Quality Variation Reduction Solution
This is a solution intended for the operation management and production departments that clarifies the abnormality cause. First, Yokogawa accurately understands the production environment and operation conditions where a process quality abnormality occurred, then makes a hypothesis and carries out analysis for each of the four Ms, and repeats the verification to identify hidden problems and make a new hypothesis. Based on these results, Yokogawa clarifies the mechanism of how the process quality abnormality occurred and suppresses the variations in the quality.

Optimal Parameter Design Solution
This is a solution intended for the production engineering administration department, which analyzes the process quality abnormality causes from the process data and proposes improvements, and then provides a solution to quickly find the combination of operation parameter values to optimize the quality. Thus, the development speed can be increased and high-quality products can be released to the market quickly, resulting in increased market competitiveness.

Real-Time Quality Monitoring
A real-time monitoring environment is required to keep the product quality high. This solution provides an asset that allows the production department to produce high-quality products while checking for deviations in the quality, and allows the quality management department to monitor the quality in the plant in real-time.

QUALITY STABILIZATION SOLUTIONS AND MT METHOD
Quality stabilization solutions analyze data to find process quality abnormality factors. There are multivariable analysis techniques such as regression analysis and principal component analysis (PCA) that statistically handle multiple pieces of data. The quality stabilization solutions use the MT method as the main technique for determination/prediction. However, analysis is carried out using not only the MT method but also using the best technique to solve customer problems. The following outlines the MT method and describes how to use it.

What is the MT Method?
“MT method” is an abbreviation for Mahalanobis-Taguchi Method. “Mahalanobis” refers to Dr. P.C. Mahalanobis, an Indian statistician. A distance measure based on correlations between variables introduced by Dr. Mahalanobis is called the Mahalanobis distance (MD). Meanwhile, “Taguchi” refers to Dr. Genichi Taguchi, who is well known as the founder of quality engineering (Taguchi method).

The MT method is an information processing method derived from quality engineering and is one of the pattern recognition methods that incorporate the Mahalanobis distance measure into the quality engineering system. It calculates the distance between the reference data and a sample to be determined as a Mahalanobis distance and determines the difference quantitatively.
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Using the MT Method Effectively

The following example describes how to apply the MT method to the process abnormality determination, as shown in Figure 3.

Reference Space

First, collect the process data during normal operation and then create a reference space that maintains the normal correlation between the process variables to quantitatively determine the normal and abnormal.

Sample to Be Determined

Next, prepare the process data for which you want to determine differences in the process behavior and use the data as a sample to be determined.

Mahalanobis Distance Calculation

Finally, calculate the Mahalanobis distance for the sample to be determined in the reference space.

Refer to the graph at the bottom in Figure 3, where the vertical axis indicates the Mahalanobis distance per unit time and the horizontal axis indicates the time. The parts where the Mahalanobis distance increases indicate that the same graph pattern does not exist in the reference space. This indicates that the behavior of the plant differs from the behavior in the reference space.

The use of the MT method as a pattern recognition method of the process data in this way enables quality abnormality determination, abnormality sign detection, and continuous monitoring. In addition, an increase in the operating speed of a computer increases the speed of the feedback process from abnormality detection to response and enables real-time processing in the process control.

YOKOGAWA’S PROBLEM-SOLUTION APPROACHES

Quality stabilization solutions have been applied to the quality stabilization challenges described above. The following presents their case examples.

Reduction of False Detection (Quality Abnormality Determination Solution)

Problem Identification

A quality management system used vibration data to monitor the surface conditions of products, and its false detection (determination of non-defective products as defective products) rate was high. Therefore, many products had to be inspected in the final inspection process and productivity improvement was required.

Figure 3 Overview of MT method
Analysis
After performing feature quantity (that distinguishes between non-defective and defective products) and Yokogawa's unique data classification processing, the MT method was applied to the system in order to reduce the false detection rate. As shown in Figure 4, one variable that deviates from the control value was determined (by the MT method) and the disruption of the correlation between two or more variables was also evaluated at the same time. This enabled the advanced determination and helped reduce the false detection rate.

Problem Solution Proposal
New control key performance indicators (KPIs) were used to reduce the false detection rate to less than a few percent and helped reduce the work load at the final inspection.

Figure 4 Abnormality determination by feature quantities

Predictive Detection of Asset Failure (Abnormality Sign Detection Solution)

Problem Identification
Deteriorating monitoring data (indicating the asset conditions) in the product processing process resulted in the clogging of pipes, and asset problems need to be prevented.

Analysis
Comparison of the cause data (indicating the cause of the asset failure) with the monitoring data shown in Figure 5 could not identify signs that would help prevention. As a result, clogging could not be prevented and there was no choice but to remove the clogging based on the monitoring data. So Yokogawa's unique data pre-processing was applied using the cause data to calculate the quality sign KPI (Mahalanobis distance) and it was found that a change occurred in the quality sign KPI several hours before a change occurred in the monitoring data.

Problem Solving Proposal
KPI using the Mahalanobis distance was proposed as a new failure sign detection system that replaces the previous monitoring data. This enables detecting failure signs, and asset failures can be prevented by taking preventive measures.

Figure 5 Sign detection by Mahalanobis distance

Prevention of Variation in Raw Material Specific Consumption (Quality Variation Reduction Solution)

Problem Identification
There were variations in the ratio of the product production quantity to the raw material input quantity (raw material specific consumption), so it was difficult to ensure a stable production while keeping the unit price for raw materials low. However, it was hard to identify the cause factors, as the process that includes the raw materials and products was large.

Analysis
Data for the entire manufacturing facility and all processes was checked but it was difficult to identify the cause factors because various factors were intricately involved. Analysis was carried out by applying Yokogawa’s unique data pre-processing with a special focus on a causal relationship of the processes, and multiple variation factors in each process was able to be identified. A measure was taken for one of those factors and the variation in the specific consumption was able to be reduced by several tens of percent as shown in Figure 6. Furthermore, the process and asset was able to be stabilized at the same time, which helped reduce the operator’s work load.

Problem Solution Proposal
A measure to prevent the in-process variations was taken and, as a result, the asset was stabilized and the raw material specific consumption was improved.

Figure 6 Reduction of measured value variation
Calculation of Optimal Production Parameter (Optimal Parameter Design Solution)

Problem Identification
A product met the quality requirements but was less advantageous in the quality compared to that of competitors’ products, so there was a strong need to improve the quality. A probable hardware measure was to modify the asset and a probable software measure was to optimize the production conditions. Hardware improvement costs a lot of money for investment, and a production condition optimization approach was taken as a cost-effective way to improve the existing process software.

There were multiple quality management items in a process in the product development process of the customer. At this point, the quality and the production condition optimization were in a trade-off relationship. However, both could not be improved at the same time because the causal relationship between the quality and the production conditions could not be quantitatively visualized.

Analysis
The target quality values could not be achieved under the existing production conditions, so the experiment data under new production conditions was evaluated. There were some operational limitations in multiple production parameters related to the quality, so a production experiment was conducted using a model-based design of experiment other than that using an orthogonal table.

Furthermore, data obtained by production experiments under various production conditions was used to carry out analysis using a smooth response surface methodology to clarify the causal relationship between the production conditions and multiple qualities in a trade-off relationship.

Then, multi-objective optimization was applied to achieve the quality to satisfy the requirements, and multiple production conditions well balanced with other qualities was able to be calculated.

Problem Solution Proposal
Verification experiments were conducted under multiple production conditions and it was verified that the target quality values that satisfy the requirements was able to be achieved.

The use of these analysis results enabled construction of a production system that can switch the production conditions flexibly when there was a different requirement for the quality.

CONCLUSION

The production process must always be changed to respond to changes in the raw materials and meet the high product quality standards. For that purpose, speed and accuracy are required for quality improvement.

Recently, there are a large number of various kinds of data analysis software that are easily available. However, various problems that occur before and during the execution of data analysis must be solved to correctly execute the analysis techniques provided by these software products.

As described above, Yokogawa has analysis techniques and know-how and provides problem solving approaches to stabilize the quality. The most important thing is to use techniques verified based on the engineering knowledge of Yokogawa’s analysts. We believe new discoveries lead to knowledge over the course of providing the data analysis service to solve customer problems using three core techniques: “Data Classification and Pre-Processing,” “Analysis Techniques and Tools,” and “Analysis Approaches” as shown in Figure 7.

We will provide quick services ranging from problem identification through to problem analysis based on the accumulated process data in cooperation with customers.

REFERENCES