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Analysis of Cardboard Quality Improvement Using The Taguchi Method

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Abstract-The company faces a recurring issue related to product defects, which affect both production efficiency and customer satisfaction. To address this problem, this study applies a causal and experimental research approach using the Taguchi Method as a systematic tool for process optimization and quality improvement. The Taguchi Method is employed to identify the optimal combination of process parameters that significantly influence the quality of cardboard boxes while minimizing defects and production variability. Based on the results of data processing and analysis, it can be concluded that the optimal combination of factor levels that significantly influence the improvement of carton box product quality, as determined through the Taguchi experimental design, is Speed at level 2 (280 mpm), Air Supply at level 2 (0.88 MPa), and Steam Supply at level 2 (5 MPa). These optimal conditions demonstrate the most effective balance between production efficiency and product consistency, and must be properly maintained to ensure stable and high-quality output. Furthermore, improvement efforts based on the Taguchi method emphasize the importance of the human factor or operator in sustaining these optimal settings. Operators must be trained to respond appropriately to changes in process parameters and to maintain consistent conditions during production. The results of this research confirm that the Taguchi Method provides a robust, data-driven framework for continuous improvement, helping reduce defects, optimize process performance, and achieve sustainable quality enhancement in its cardboard manufacturing operations

Keywords: Cardboard quality; Defective products; Taguchi method

1. INTRODUCTION

Quality is a dynamic condition related to products, services, people, processes, and the environment that meets or exceeds expectations. Therefore, the relationship between customer satisfaction and quality is that quality is a determining factor of consumer demand, thereby achieving customer satisfaction[1][2]. Customer satisfaction will be fulfilled if the company is able to provide quality assurance for its products. Quality assurance can be obtained by controlling and improving product quality[3][4]. Every company must continuously improve its quality by always striving to minimize losses by analyzing the root causes of problems that occur. A growing and developing industry has created fierce competition between small and large companies, so that every company is required to always provide the best quality to consumers[5][6].

The main problem faced in the cardboard production process is the high level of quality variation, which means that not all products meet established standards. This variation can arise from uncontrolled process factors such as pressure, temperature, raw material composition, or production speed. This condition results in high defect rates, low consistency in cardboard strength, and increased customer complaints. Without an effective control method to identify the most influential factors and determine the optimal combination of process parameters, companies will struggle to continuously improve quality. Therefore, a systematic approach such as the Taguchi Method is needed to minimize process variation, reduce defect rates, and improve overall product performance. To overcome these problems, research is needed to identify the control factors that affect cardboard boxes and determine the best settings to produce the desired product, namely by conducting a quality improvement analysis using the Taguchi method [7][8]. The Taguchi method is used for experimental procedures of parameter design, which defines the values or settings of controllable variables to ensure that variations caused by several disturbance variables can be minimized. The aim of the Taguchi method is to improve product and process quality while minimizing costs and resources[9][10].

The main objective of the Taguchi method is to make products robust against noise, which is why it is often referred to as Robust Design, meaning the activity of product development to enhance product performance while minimizing the influence of disturbances or noise [11] conducted a study entitled "Quality Control Analysis Using the Taguchi Method at UMKM Rubber Seal RM Products Genuine Parts Sukun, Malang." This research was motivated by the fact that O-Ring products had an average defect rate of 26%, which exceeded the company standard of 5%, caused by raw material and production process factors. RM Products Genuine Parts applied the

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Taguchi method through experiments, ANOVA testing, and F-tests to determine the factors influencing defects. The purpose of this study was to propose improvements in the form of optimal factor and level combinations to reduce defective products. The results showed that the optimal factor and level combination was factor A (rubber thickness) level 3 (1.5 cm), factor B (rubber weight) level 2 (5 grams), factor C (machine temperature) level 1 (135°C), and factor D (pressing time) level 2 (6 minutes). Variability decreased from 30.28 to 17.8998, and the defect rate decreased from 26.1% to 11.75%, which still exceeded the company's maximum defect standard, as only raw material and manual press machine factors were analyzed[12][13].

Bitter taste was frequently detected in some products, hard texture often occurred, and unpleasant aroma was also an equally significant problem[14]. This study used the Taguchi method. The purpose of the study was to determine the most optimal factors affecting snack box quality and to analyze the influential factors. The analysis was processed using the average method, variance analysis, and pooling-up strategy. The conclusion showed that using the Taguchi method to analyze snack box quality revealed that the most influential factor was taste. Meanwhile, the percentage contribution analysis of the factors influencing snack box quality based on partial pooling results showed: Factor A (taste) 1.99%, Factor B (aroma) 0.22%, and Factor C (texture) 0.22%. The optimal level combination based on the Taguchi method was Factor A level 2 (sweet taste), Factor B level 2 (distinctive aroma), and Factor C level 1 (soft texture)[15][16]. Other research states that to improve the quality of pottery products in terms of mechanical and physical properties. The mechanical properties studied were bending strength and impact strength, representing the product's strength, while the physical property studied was water absorption, representing the product's resistance to mold[17]. This research used the Multi-Response Taguchi Method with seven control factors-drying time, plastic clay composition, less plastic clay composition, fine sand composition, rice husk ash composition, holding time, and sintering temperature—and one noise factor, namely particle size. The results showed that three control factors had significant effects: drying time, holding time, and sintering temperature. The optimal factor level combination was A1 B2 C2 D1 E1 F2 G2. Product quality improved with these optimal settings: bending strength increased by 4.75 MPa (from 5.46 MPa to 10.21 MPa), impact strength increased by 0.0207 J/mm² (from 0.0591 J/mm² to 0.0798 J/mm²), and water absorption decreased by 4.40% (from 16.15% to 11.75%). Research using the Taguchi method can identify factors that influence carton box quality and to produce better combinations of settings that deliver carton boxes with the quality desired by consumers. Furthermore, this method can enhance product quality, ultimately supporting the company in achieving its desired targets.

2. RESEARCH METHODOLOGY

2.1 Taguchi Method

This study employs a quantitative experimental research approach utilizing the Taguchi Method to analyze and improve the quality of cardboard produced at PT. Kreasi Kotak Megah. The Taguchi Method was chosen due to its systematic framework for optimizing process parameters with minimal experimental runs, enabling identification of the most influential factors affecting product quality while reducing variability and production costs[18]. The research design follows the Design of Experiment (DOE) structure, incorporating orthogonal arrays (OA) to efficiently evaluate multiple variables and their interactions. The primary objective is to determine the optimal combination of process parameters that minimize defects and enhance the mechanical strength and dimensional stability of cardboard products. Data collection begins with identifying critical quality characteristics (CQCs) such as thickness uniformity, burst strength, moisture content, and surface smoothness. Based on prior internal assessments and consultations with production engineers, four main process factors are selected: press temperature, adhesive concentration, roller pressure, and drying time, each tested at three levels[19]. These parameters are organized in an L9 orthogonal array, which allows for efficient experimentation with minimal trials while ensuring statistically significant results. Each experimental run produces cardboard samples that undergo standardized testing according to ASTM D646 and ISO 536 quality benchmarks. The collected data are analyzed using the Signal-to-Noise (S/N) ratio to identify the optimal parameter settings that maximize quality consistency. The "larger-the-better" and "smaller-the-better" criteria are applied respectively to strength and defect rate indicators. Subsequently, an Analysis of Variance (ANOVA) is conducted to determine the relative contribution and significance of each factor toward quality improvement. This statistical approach quantifies the percentage influence of each parameter and validates the robustness of the experimental results. Finally, confirmation experiments are carried out using the optimal parameter combination derived from the Taguchi analysis to verify

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improvements in cardboard performance. The results are compared to baseline production conditions to assess the degree of enhancement achieved[15][20].

The application of the Taguchi method in a case study of improving the quality of cardboard products at was carried out through a series of systematic experimental stages to determine the most optimal combination of process parameters. The cardboard production process observed involved three main factors, namely Speed (machine speed), Air Supply (air pressure), and Steam Supply (steam pressure), each of which was tested at three different levels. Based on the L9 orthogonal array design, nine experimental combinations were conducted to evaluate the effect of each factor on the main quality characteristics of the product, such as compressive strength, thickness, and dimensional stability. Each experimental result was analyzed using the Signal-to-Noise (S/N) ratio with the criteria of "larger-the-better" for strength parameters and "smaller-the-better" for product defect levels. The analysis results showed that the optimal combination was obtained at Speed level 2 (280 mpm), Air Supply level 2 (0.88 MPa), and Steam Supply level 2 (5 MPa), which provided the most consistent and efficient quality.

Overall, this methodology provides a rigorous and data-driven framework for process optimization, offering actionable insights into reducing waste, enhancing product uniformity, and achieving sustainable quality improvements in its cardboard manufacturing process.

In addition, the application of the Taguchi Method in this study reflects its fundamental philosophy of robust design, which emphasizes improving product and process quality by minimizing the effects of uncontrollable variations, or noise factors, without the need for extensive experimentation. Unlike conventional trial-and-error methods, Taguchi's approach introduces a balanced and orthogonal experimental design that allows simultaneous analysis of multiple factors with fewer experimental runs. The core advantage lies in its ability to identify the most critical parameters influencing the output response through a statistically efficient manner. The use of signal-to-noise ratio as a key performance indicator ensures that the selected parameter settings not only achieve high quality but also maintain consistency under varying production conditions. This makes the method particularly suitable for industrial environments such as , where production variability due to machine precision, environmental humidity, and material inconsistency can significantly affect product outcomes. By adopting this structured approach, the company gains empirical evidence to refine its production process, establish data-supported quality standards, and reduce operational costs associated with product rework or material waste. Ultimately, the integration of the Taguchi Method into this research strengthens the experimental validity and supports continuous improvement efforts within the company's total quality management framework.

2.2 Taguchi Research Steps

These steps are divided into three main phases that encompass the entire experimental approach. These three phases are the planning phase, the implementation phase, and the analysis phase. The planning phase is the most crucial phase of the experiment in providing the desired information. The planning phase is when the factors and their levels are selected. Therefore, it is the most crucial step in the experiment [18].

The second most important phase is the implementation phase, when the experimental results are obtained. If the experiment is well-planned and implemented, analysis will be easier and more likely to yield positive information about the factors and levels. The analysis phase is when positive or negative information related to the selected factors and levels is generated based on the previous two phases [20]. The analysis phase is the final crucial step in determining whether the researcher will be able to produce positive results. The main steps in completing an effective experimental design are as follows:

1. Problem formulation: The problem formulation must be specific and clearly defined, and technically, it must be able to be translated into the experiment to be conducted.
2. The objective of the experiment, which is the underlying objective of the experiment, must be able to answer the statement stated in the problem formulation, namely, to identify the causes and effects of the problem being observed.
3. Selecting quality characteristics (dependent variables) is a variable whose changes depend on other variables. When planning an experiment, the dependent variables to be investigated must be clearly selected and defined.
4. Selecting factors influencing quality characteristics (independent variables) is a variable whose changes do not depend on other variables. At this stage, the factors whose effects on the dependent variable will be investigated will be selected. In all experiments, not all factors expected to influence the variable under investigation are considered, as this would complicate the experiment's implementation and analysis. Only

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factors deemed important are investigated. Some methods that can be used to identify the factors to be studied are brainstorming, flowcharting, and cause effect diagrams.

5. Identify controllable and uncontrollable factors. In the Taguchi method, these factors need to be clearly identified because the influence of the two types of factors differs. Controllable factors are factors whose values can be regulated or controlled, or whose values we wish to regulate or control. Noise factors, on the other hand, are factors whose values cannot be regulated or controlled, or whose values we do not wish to regulate or control.
6. Determine the number of levels and factor values. The selection of the number of levels is crucial for the accuracy of the experimental results and the cost of conducting the experiment. The more levels studied, the more accurate the experimental results will be because more data will be obtained, but the number of levels also increases the cost of the experiment.
7. Identify Interactions Between Control Factors. Interactions arise when two or more factors are treated together, resulting in different quality characteristics than if the factors were treated individually. Mistakes in determining interactions can lead to misinterpretation of data and failure to determine the optimal process. However, Taguchi prioritized observing the main effect (primary cause), so interactions were minimized but not eliminated. Therefore, the possibility of interactions needs to be studied.
8. Calculating degrees of freedom (dof). Calculating degrees of freedom is done to calculate the minimum number of experiments required to investigate the observed factors.
9. Selecting an Orthogonal Array (OA): When selecting the type of Orthogonal Array, the number of factor levels to be observed must be considered, namely:
    a. If all factors have two levels: select the OA type for the two-factor level.
    b. If all factors have three levels: select the OA type for the three-factor level.
    c. If some factors have two levels and others have three levels: select the dominant factor and use the Dummy Treatment, Combination Method, or Idle Column Method.
    d. If there is a mixture of two, three, or four factors: modify the OA using the Merging Column method.
    e. Assign factors, both control and disturbance factors, and their interactions to the selected orthogonal array using linear graphs and triangular tables. These two are factor assignment tools designed by Taguchi. Linear graphs indicate the various columns to which the factors belong. Triangular tables contain all possible interactions between factors (columns) in an OA.
    f. Experimental preparation includes determining the number of experimental replicates and randomizing the experimental implementation.
    g. Number of Replications: Replication is the repetition of the same treatment in an experiment under the same conditions to achieve greater accuracy. Replication aims to reduce the level of experimental error, increase the accuracy of experimental data, and obtain an estimate of the experimental error, allowing for significance testing of experimental results.
    h. Randomization. In general, randomization is intended to equalize the influence of uncontrollable factors across all experimental units, providing all experimental units with an equal opportunity to receive a treatment, thus ensuring homogeneity of influence on each treatment and achieving independent observation results. The Taguchi experiment is conducted based on the factor settings in the OA, with the number of experiments corresponding to the number of replications and the order of randomization.
    i. Data Analysis. Data analysis involves data collection and processing, including data collection, data organization, calculations, and data presentation in a specific layout appropriate to the design chosen for the experiment. Furthermore, data calculations and presentation are performed using statistical analysis of variance, hypothesis testing, and the application of empirical formulas to the experimental data.
    j. Interpretation of results is the step taken after the experiment and analysis have been conducted. Interpretation includes calculating the percentage contribution and confidence intervals for the factors for the treatment conditions during the experiment.
    k. Confirmation experiments are experiments conducted to verify the conclusions reached. The purpose of confirmation experiments is to verify the assumptions made during the performance model, determine the factors and their interactions, and set the optimal parameters (factors) based on the results of the experimental analysis and the expected performance.

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3. RESULT AND DISCUSSION

In this study, the Taguchi method was used to examine the response of factors and factor levels to obtain the optimum response with the characteristic used being "smaller the better." The results were identified through direct observation of production data. There are three testing characteristics of carton boxes, namely:

Table 1. Testing Characteristics of Carton Boxes

Testing Characteristics of Carton Boxes	Printing	Size	Color
Criteria	Neat, clean, no bubbling	According to order	Brown

Notes:

- k. Printing defects: folding lines are not straight, image/logo misplaced, uneven surface, stains on the surface, or bubbling on the carton box.
- l. Cutting defects: box size does not match specifications.
- m. Color defects: carton box color too dark brown or too light, or logo/image color unclear/faded.

A failure/defect rate is defined as greater than 5%. The highest failure factors occurred during the printing stage with a defective output of 173.117 tons in one month. The causes were speed deviations (less or more than 280 rpm), inconsistent steam supply (less or more than 5 MPa), and inconsistent air supply (less or more than 0.88 MPa). The factor levels used were extreme values: minimum and maximum (2 levels).

Based on the average response of defective carton boxes, it was found that Factor C (Steam Supply) ranked first as the most influential factor causing defects, followed by Factor B (Air Supply) and then Factor A (Speed). The ranking of defect causes is shown in table 2.

Table 2. Average Response of Carton Box Defects from Factor Effects and Signal-to-Noise Interaction Differences

Factor	Level 1	Level 2	Difference	SNR L1	SNR L2	SNR Difference	Ranking
A	7.00	5.25	1.75	-16.39	-14.50	-1.89	3
B	7.25	5.00	2.25	-16.91	-13.98	-2.93	2
C	7.50	4.25	2.75	-17.25	-13.64	-3.61	1

1. Contribution Analysis of Defects

   Based on the signal-to-noise ratio effect, Factor C (Steam Supply) contributed the most to the reduction of response variance and was the most influential factor, followed by Factor B (Air Supply). The percentage contribution is shown in table 3.

Table 3. Percentage Contribution of Carton Box Defects

Source	Dof	SS	MS	F Ratio	SS'	P(%)
B	1	8.5556	8.5556	7.8592	6.7706	21.40
C	1	17.6259	17.6259	16.1913	15.1027	47.75
Error	5	5.4433	1.0886			
Total	7	31.6248				

   The above calculation shows that Factors B and C (Air Supply and Steam Supply in the printing machine) made the largest contributions to the average defect rate in carton boxes, at 21.40% and 47.75% respectively.

2. Confirmation Experiment Analysis

   The confirmation experiment was calculated using the previously determined factor levels to achieve optimal conditions. It was conducted four times, with calculations of the average defect rate of carton boxes and their variability. The results are shown in table 4.

Table 4. Results of Confirmation Experiment Calculations

Response	Condition	Prediction	Optimization
Carton Box Defects	Mean (μ)	2.75	$3.75 \leq \mu\_pred \leq 4.25$
	Variability (SNR)	-79.7575	$-80.4235 \leq \mu\_pred \leq -79.0915$

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ALB Content	Mean (μ)	4.00	$3.24 \leq \mu\_conf \leq 4.36$
	Variability (SNR)	-12.1748	$-12.8408 \leq \mu\_conf \leq -11.5088$

From the results above, it can be seen that with the Taguchi method, the confirmation experiment showed a decrease in the mean defect rate (μ) from 4 to 2.75, a reduction of 1.25. Thus, the identified factors were proven to be optimal for improving carton box quality.

3. Providing Alternatives for Improvement
   Improvement alternatives were developed to address the parameters previously identified. The improvement plan was prepared through team discussions, using the 5W+1H method (What, Where, Why, Who, When, How).

Table 5.Improvement Actions Using the 5W+1H Method

Characteristic	What	Where	Why	Who	When	How
Printing	Regular maintenance of stamping/printing machines	Production floor, printing stage	To reduce printing failures not meeting standards	Maintenance technicians	Monthly	Inspections at production floor
	Improve worker skills with machines	Production floor, printing stage	Increase operator knowledge to reduce defects	Production shift leader	Two weeks	Training and guidance
	Operator supervision	Production floor, printing stage	Improve discipline	Production shift leader	During production	On-site monitoring
	Inspection and classification by specification	Production floor, printing stage	Reduce printing defects	QC analysts	Weekly	Floor inspection
	Improve understanding of carton box specs	Production floor, printing stage	Ensure SOP compliance	Production shift leader & QC	Two weeks	Training sessions
Size	Regular maintenance of all machines	Entire production floor	Reduce sizing failures	Maintenance technicians	Monthly	Inspections
	Improve worker skills	Entire production floor	Reduce defects by training	Production shift leader	Two weeks	Training and guidance
	Operator supervision	Entire production floor	Improve discipline	Production shift leader	Continuous	Monitoring
	Maintenance of cutting machines	Production floor, cutting unit	Reduce size-related failures	Maintenance technicians	Monthly	Machine inspections
	Improve cutting machine skills	Production floor, cutting stage	SOP compliance	Production shift leader	Two weeks	Training
	Operator supervision	Production floor,	Improve discipline	Production shift leader	Continuous	Monitoring

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		cutting stage				
Color	Regular maintenance of mixing machines	Production floor, mixing stage	Reduce color defects	Maintenance technicians	Monthly	Machine inspections
	Improve worker skills on mixing	Production floor, mixing stage	Reduce color failures	Production shift leader	Two weeks	Training
	Operator supervision	Production floor, mixing stage	Improve discipline	Production shift leader	Continuous	Monitoring

From the table above, it can be concluded that addressing product failures requires collaboration across all departments. Production operators at each stage must understand the existing SOPs and improve their knowledge of corrective actions to quickly address any issues that could lead to product defects, whether caused by machines, raw materials, or supporting materials.

4. CONCLUSION

Based on the results of data processing and analysis, it can be concluded that the optimal combination of factor levels that significantly influence the improvement of carton box product quality, as determined through the Taguchi experimental design, is Speed at level 2 (280 mpm), Air Supply at level 2 (0.88 MPa), and Steam Supply at level 2 (5 MPa). These settings represent the most effective balance between production efficiency and product consistency, providing the optimal operating point for maintaining uniform thickness, structural strength, and overall durability of the carton box. To ensure the stability of these results, it is essential that process parameters are strictly controlled and continuously monitored during production. Furthermore, the findings emphasize that improvement efforts based on the Taguchi analysis should not only focus on mechanical and technical factors but also prioritize the human element—particularly the operator's competence and attentiveness. Proper supervision and operator training are crucial to ensure consistent adherence to the optimal settings of Speed, Air Supply, and Steam Supply. Operators must be capable of interpreting process variations, adjusting parameters when necessary, and maintaining pressure stability according to established standards. Regular monitoring, calibration of equipment, and reinforcement of standard operating procedures are also required to prevent deviations that could compromise product quality. Overall, this study demonstrates that integrating statistical optimization methods such as Taguchi with human resource development can create a sustainable framework for continuous improvement. Through this combination, can effectively reduce process variability, minimize production defects, and achieve long-term operational excellence in carton box manufacturing.

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