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Statistical Analysis for Weaving Quality using ANOVA: A Case Study

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Abstract

This research investigates the critical challenges faced by various industries in sustaining profitability amidst escalating process defects. Despite enhancements in management systems aimed at quality improvement, numerous sectors continue to confront issues stemming from outdated machinery, ineffective processes, and inadequate employee training. Conventional methods, such as enhanced quality control and workforce training, have often resulted in increased production costs without substantial reductions in defects, highlighting the necessity for a more effective approach. This study employs Analysis of Variance (ANOVA) to pinpoint the significant variables contributing to quality variance in the weaving process. The findings indicate that width and length are primary factors, accounting for over 45.22% of quality variance, while thread type contributes 23.06%. Additionally, factors such as the thickness of metallic threads and weight per unit have lesser impacts. This analysis empowers industries to concentrate their optimization efforts strategically, thereby fostering enhanced quality and overall profitability.

Keywords
Statistical analysis; Analysis of variance; Defects; Quality case; Weaving process

1. Introduction
According to (Adedeji et al. 2023), defects in processes pose important problems for industries around the world. Despite innovations in modern management systems aiming to reduce these defects, many industries continued to face persistent quality challenges (Yaprak and Vergili 2023). This implies that simply adopting new technologies or management strategies is inadequate, effective implementation and organizational change toward quality monitoring and improvement are required (Reda and Dvivedi 2022). The situation is particularly serious in Indonesia's weaving industry, where traditional management practices are prominent (Feri, Sudarmiatin, and Mukhlis 2022). The industry's capacity to adapt to new quality management principles has been hampered by its reliance on antiquated approaches (Pratiwi and Dachyar 2020).

Furthermore, the weaving industry encounters particular difficulties due to a lack of effective statistical techniques for data collection and analysis (Tripathi and Gupta 2021; Zonnenshain and Kenett 2020)(Tripathi and Gupta 2021). This capability gap means that many industries lack the knowledge and experience required to identify and prevent defects consistently (Psomas, Fotopoulos, and Kafetzopoulos 2011). Resource constraints and a general lack of quality management skills drive these industries to prioritize order fulfillment and rapid delivery, often at the expense of overall product quality (Addis, Dvivedi, and Beshah 2019; Kang and Bhatti 2019). As a consequence, there is an urgent need for complete quality management improvements, which include the integration of statistical techniques and up-to-date tools (Garza-Reyes 2018).

Recently, the increase in process defects in the industry has caused significant concern among industries, requiring investigation into the root causes. These defects can be traced back to a variety of causes, including outdated machinery, inefficient procedures, and inadequate training of workers. Although numerous approaches have been attempted to address these problems, such as improving quality control systems and improving workforce education, many of these approaches have resulted in increased production expenses without a significant reduction in defect rates. The increased rework required not only delayed production deadlines, but also extended resources, resulting in decreased efficiency and profitability.

To properly address these problems, this research uses analysis of variance (ANOVA) as a form of statistical analysis (Athreya and Venkatesh 2012; Shrestha and Manogharan 2017). ANOVA is particularly effective in comparing the means of different groups and determining whether there are statistically significant differences between them (Shinde and Arakerimath 2023; Xiong and Feng 2022). Using this technique, the research aims to identify essential factors that lead to quality variance in the weaving process. This technique is critical for identifying particular parts that require improvement and driving targeted treatments that may lead to more effective defect reduction strategies.

This research uses analysis of variance to further investigate the influences on weaving quality. The use of the signal-to-noise ratio (S/N) in this analysis provides another layer of information to evaluate how different factors affect the consistency of the output. The S/N ratio is particularly useful for identifying disruptive factors that might otherwise go undetected in traditional analysis. This research integrates these statistical techniques and develops a thorough understanding of the factors that impact problems in the weaving industry, creating opportunities for improved decision making and quality management practices. This holistic aim is supposed to not only indicate the root causes of problems, but also allow for easier to implement more effective quality improvement activities.

2. Methodology

2.1 Data and Material

This research utilizes data specifically related to defects that occurred during the weaving process, with a primary focus on quantifying these defects. The data set, carefully recorded by skilled and experienced weavers, offers a reliable and comprehensive source of information. Since weavers were intimately familiar with the process, detailed tracking of defects ensures accuracy and relevance. However, it focuses on these well-documented data, the study aims to effectively analyze the root causes of defects and provide information to address and minimize them within the designated time period.

2.2 Minitab Statistical Software

The latest version of Minitab Statistical Software, 17.2.1, released on March 17, 2015, provides an extensive suite of statistical tools designed to empower users with a variety of analytical capabilities. This version supports functionalities such as regression analysis, multivariate analysis, variance analysis, and statistical process control, making it a comprehensive resource for data-driven decision-making (Alzahougi, Demir, and Elitas 2023). Fully compatible with the Windows operating system, Minitab 17.2.1 is a powerful and versatile tool that facilitates a wide range of statistical analyses. Its user-friendly interface and features make it ideal for various applications in research, quality control, and data analysis, allowing organizations to effectively use statistical insights to improve processes and results (Singh, Gill, and Mahajan 2023).

2.3 Methodology

The methodology for this statistical analysis involves performing an analysis of variance (ANOVA), which provides a comprehensive statistical evaluation of the experimental data. This begins to identify the quality characteristic of the process. The detailed research methodology for this statistical analysis is effectively summarized in Figure 1.

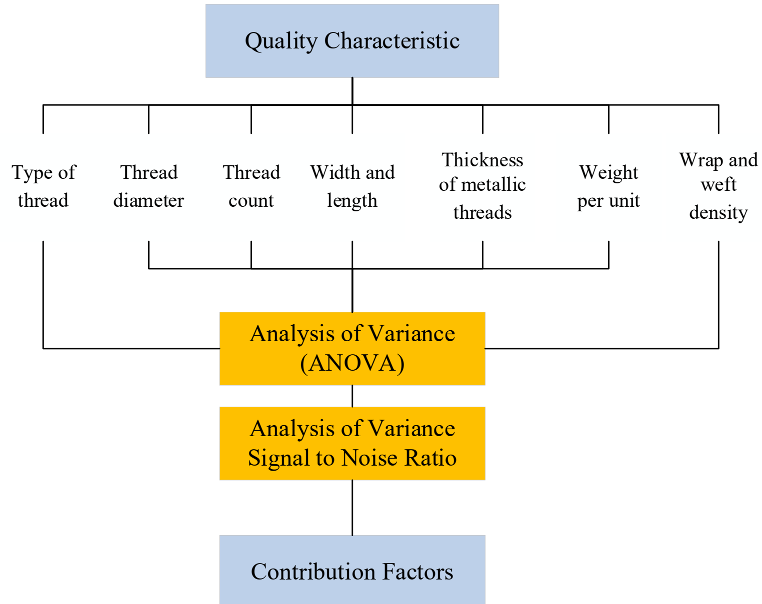

Figure 1. Methodology

This analysis is critical for understanding the variability in the data, enabling to identify how much each factor influences the overall outcomes. Through ANOVA, the research gains valuable insight into which variables contribute meaningfully to observed differences, ensuring a deeper understanding of the dynamics of the analysis (Kumar Karna, Vijay Singh, and Sahai 2012; Sahoo et al. 2023).

3. Result

3.1 Factor and Result

A factor is purposely kept constant during an analysis to minimize its potential influence on the result being measured. Controlling these factors allows one to isolate the effects of other independent factors and verify that any observed changes in the results are directly attributable to those factors rather than other influences. Table 1 emphasizes the relationship between factors and results by presenting data that demonstrate how maintaining certain factors constant might lead to more reliable and valid analysis conclusions. This systematic approach is essential to improve the precision of the analysis, ultimately contributing to an improved understanding of the dynamics that occur in the analysis.

Table 1. Factor and Result

Experiments	Factors							Result
	1	2	3	4	5	6	7	$\bar{y}$
Y_1	A	A	A	A	A	A	A	1.5
Y_2	A	A	A	B	B	B	B	7.5
Y_3	A	B	B	A	A	B	B	4.0
Y_4	A	B	B	B	B	A	A	6.0
Y_5	B	A	B	A	B	A	B	1.5
Y_6	B	A	B	B	A	B	A	3.0
Y_7	B	B	A	A	B	B	A	3.0
Y_8	B	B	A	B	A	A	B	4.0

3.2 Analysis of Variance (ANOVA)

The influence of the metric for the means delineates the degree to which each autonomous factor affects the fluctuations of the dependent variable (Singh, Gill, and Mahajan 2023). Illustrated in Figure 2 is an exhaustive

examination of these influence metrics, systematically ranking each impacted factor engaged in the statistical inquiry. These influence metrics offer a numerical assessment of the contribution each factor makes to the ultimate outcome, thereby illuminating its comparative significance. The ensuing ranking framework arranges these factors based on their importance, clarifying their precedence within the analytical context.
The results illustrated in Figure 2 demonstrate notable findings in the context of the "Smaller is better" approach. It presents the results of the pooled factors for the means.

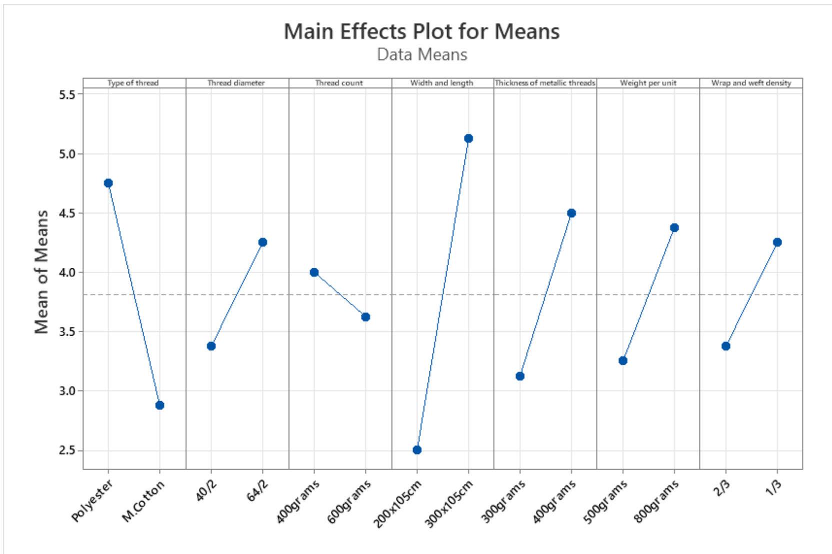

Figure 2. Response for Means

Within the pooling methodology, the process initiates with an F-test designed to juxtapose the variance of the smallest factor against that of the next largest factor. Should the F-test reveal no substantial discrepancies, the two variances are amalgamated, resulting in a new pooled variance that is subsequently employed to assess the following larger factor. This cyclical approach persists, with variances being aggregated and evaluated in succession, until a noteworthy F value is obtained (Table 2).

Table 2. Pooling Up Factor for Means

Factor	SS
1	7.030
2	1.530
3	-----------*Pooling Up*---------
4	13.780
5	3.780
6	2.530
7	1.530
Residual Error	0.009

3.3 Analysis of Variance Signal to Noise Ratio (S/N Ratio)

This analysis is to reduce variability and achieve smaller values for the response variable, indicating an improvement in quality (Ahmad and Basu 2023; Haniza et al. 2018). Table 3 offers a comprehensive overview of the results obtained to employ the "Smaller is Better" approach, framed within the context of signal-to-noise (S/N) ratios. This analysis acts as an essential tool for evaluating the effectiveness of strategies to minimize variability and improving the desired result, ultimately aligning with the larger goal of quality improvement (Beattie and Sohal 1999).

Table 3. Signal to Noise Ratio Result

Experiments	Smaller is Better
1	-3.979
2	-17.520
3	-12.041
4	-15.563
5	-3.979
6	-11.139
7	-10.000
8	-13.010
Total	-87.231

Impact factors are critical metrics that emerge from analyzing signal-to-noise (S/N) ratios, serving as a quantitative tool to assess how each factor contributes to variations in outcomes and overall quality (Salma et al. 2023; Taguchi and Tsai 1995). The identification and prioritization of the most influential factors impacting a desired response variable to improve decision-making and process optimization. The detailed breakdown presented in Table 4 illustrates the varying significance of these factors, providing valuable information.

Ultimately, this plot for S/N ratio is to create a more stable environment where the desired factors can exert their influence more effectively, thereby optimizing performance and outcomes in the analyzed system (Mohapatra et al. 2023; Walia, Shan, and Kumar 2006). Figure 3 emphasizes the importance of reducing unwanted variability in the analysis, which is crucial for enhancing overall performance.

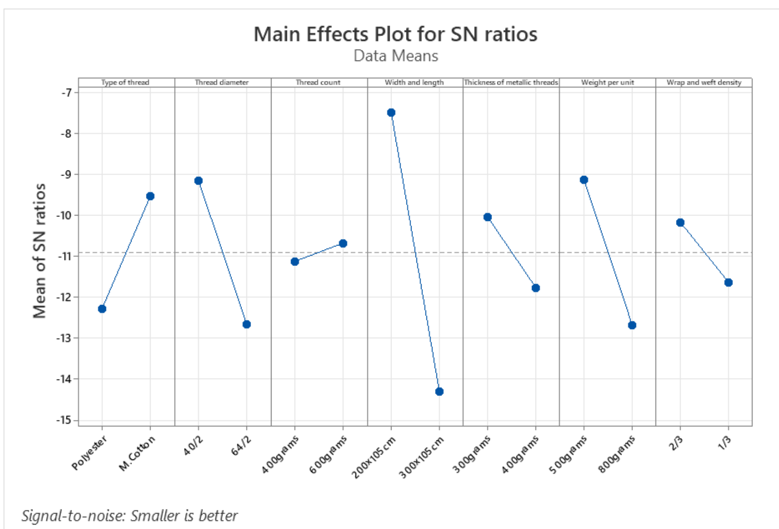

Figure 3. Response for Signal-to-Noise (S/N) Ratios

Table 5 explains the process for pooling components in the context of signal-to-noise (S/N) ratios, focusing on the statistical analysis of sums of squares (SS). In this analysis, the Tread Count component had the highest impact, showing an immediate correlation with the expected outcome. This identification is critical because it determines which variables need extra attention and allocation during the investigation (Hosokawa and Miyagi 2019; Mitra et al. 2016).

The pooling technique assists in organizing data related to the Tread Count factor, leading to a better understanding of its impact on S/N ratios. The analysis highlights Tread Count's essential significance, showing its value not only as an individual aspect, but also as a key contributor to overall system performance. This focused approach ensures that attempts to increase performance are more effectively directed, as optimizing Tread Count may result in higher quality and lower variability in the results, encouraging more predictable outcomes in the evaluated processes.

Table 4. Pooling Up Factor for Signal-to-Noise (S/N) Ratios

Factor	SS
1	15.06
2	24.48
3	-----------*Pooling Up*---------
4	92.71
5	5.94
6	25.09
7	4.31
Residual Error	0.69

Table 5 provides a detailed breakdown of the percentage contributions of various control factors to the optimization process. Width and length stand out with a combined contribution of 45.22%, demonstrating that these dimensions are important in producing the intended results. Their high impact shows that addressing these factors could result in significant performance improvements, making them important targets for optimization efforts.

Following width and length, the type of thread accounts for 23.06%, highlighting its relevance in shaping the qualities of performance. Meanwhile, the thickness of the metallic threads and the weight per unit contribute 12.39% and 8.29%, respectively. This separation allows to focus efforts on the most important components, while also recognizing that even smaller contributions can play a significant role in the overall optimization strategy, ensuring a complete approach to increasing quality and performance.

Table 5. Contribution

Factor	F Ratio	SS'	C (%)
1	1562.2	7.0255	23.06
2	340.0	1.5255	5.01
3	62.2	0.2755	0.90
4	3062.2	13.7755	45.22
5	840.0	3.7755	12.39
6	562.2	2.5255	8.29
7	340.0	1.5255	5.01

4. Discussion and Conclusions

Today, industrial have significant challenges that some industries worldwide must address to maintain profitability. While there are improvements in management systems designed to minimize these defects, many industries still face these quality issues. In the beginning, industry increase in process defects has concerned, prompting industry to investigate the root causes more seriously. These defects are often caused by various factors, including outdated machinery, inefficient workflows, and inadequate employee training. Although some strategies have been attempted, such as improving quality control measures and improving workforce development, many have led to increased production costs without corresponding improvements in defect rates. Consequently, the need for a more targeted and effective approach is urgent.

To address these quality challenges, this research employs analysis of variance (ANOVA), a robust statistical method. Industries have applied ANOVA to identify key factors that contribute to variance in quality in the weaving process. This analysis allows for the comparison of different variables to determine which have the most significant impact on process results. Industries have checked the critical variables and materials that are related to defect rates, which are essential to develop targeted results. Understanding these relationships is vital to implement effective strategies that improve quality and reduce defects.

The findings indicate that width and length contribute more than 45.22% to the variance in quality outcomes, establishing them as crucial areas for optimization. Improving these variables can increase performance and defect reduction efforts. Additionally, the type of thread accounts for 23.06% of the quality variance, further emphasizing its importance in the weaving process. Other factors, such as the thickness of metallic threads and weight per unit, while contributing smaller percentages, remain significant and should not be neglected. This detailed analysis enables industries to focus on optimization efforts, ensuring a comprehensive approach to improving profitability.

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Data Availability
Data and material will be given when a request has been made

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Conflict of Interest
There is no conflict of interest by the authors

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