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Analysis of Wood Powder Product Defects Using Six Sigma DMAIC and Failure Mode Effect Analysis Methods

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ABSTRACT

CV. XYZ is a supplier of waste wood powder, specifically utilizing Merbau wood. The company currently faces product quality issues, including powder mixed with other sizes (43.2%), foul odor and mold (16.2%), and excessive moisture/wetness (40.6%). This study aims to analyze and improve product quality using Six Sigma and FMEA methods. The results indicate an average DPMO value of 40,621 with a Sigma level of 2.46, suggesting that the process is not yet optimal. The FMEA analysis identified the machine factor as the primary cause of defects, with the highest Risk Priority Number (RPN) of 540. Improvement recommendations include machine recalibration, scheduled cleaning, and preventive maintenance. The implementation of these strategies is expected to reduce defects and enhance the company's competitiveness. This research contributes to quality control in the wood powder waste processing industry and opens opportunities for further research into developing more effective systems.

Keywords: *Defects, Six Sigma, DMAIC, FMEA, Quality Control, Product Defects*

Introduction

CV. XYZ is a supplier company that collects manufacturing waste in the form of wood powder, specifically Merbau wood waste, from various factories. This material is then distributed to factories that require wood powder as their primary raw material, such as pallet and briquette manufacturers. The company faces quality control challenges, as defects are found in every wood powder processing batch. These defects include powder mixed with other sizes (27,142 kg or 43.2%), foul-smelling and moldy powder (10,165 kg or 16.2%), and wet powder (25,522 kg or 40.6%). In the current industrial landscape, competition is growing rapidly in both local and international markets. Attention to quality issues is a key factor in winning industrial competition in the era of globalization. Quality encompasses everything that satisfies consumers or meets their needs. Therefore, for consumers, quality is a critical factor in the selection of a product or service.

To address the issues occurring at CV. XYZ, this research employs the Six Sigma and Failure Mode and Effect Analysis (FMEA) methods. Six Sigma is a process of continuous improvement aimed at reducing product defects, prioritizing the DMAIC stages (Define, Measure, Analyze, Improve, Control) [1]. DMAIC is a comprehensive approach to quality control and improvement, starting with identifying problems through management and providing improvement suggestions [2]. Literature studies indicate that the application of this method has proven effective in raising quality standards across various global manufacturing sectors, including the wood processing and furniture industries which share similar material characteristics [3], [4]. Furthermore, recent research in 2025 indicates that integrating Six Sigma methods into manufacturing product quality control can significantly suppress process variability [5], [6].

FMEA is used to evaluate failures occurring in a system, design, process, or service [7]. Other studies in the paper industry [8] and automotive components [9] also emphasize that FMEA integration is crucial for mitigating fatal defect risks early by detecting potential failure modes. FMEA identifies and prioritizes the likelihood of failures or product defects to enhance customer satisfaction. In calculating risk, FMEA uses the Risk Priority Number (RPN) indicator, comprising (S) Severity, (O) Occurrence, and (D) Detection [10].

However, there is still a research gap regarding the specific integration of Six Sigma and FMEA methods in the waste wood powder processing industry, particularly for Merbau wood, which possesses unique physical and chemical characteristics. Additionally, few studies have examined quality control within the context of the industrial waste supply chain to production sectors such as pallets and briquettes, where raw material variability is high and directly impacts the final product quality. This research also provides practical contributions for similar companies in designing data-driven quality control systems to significantly reduce defect rates. Therefore, the objective of this study is to provide improvement recommendations and sustainable quality control strategies for CV. XYZ to increase consumer satisfaction and company competitiveness in both local and international industrial markets.

Although Six Sigma and FMEA methods have been widely applied in various manufacturing industries, previous studies predominantly focus on discrete manufacturing products or finished goods quality, with limited attention to raw material waste processing industries. In particular, studies discussing quality control of wood powder waste remain scarce, especially those considering the unique physical and hygroscopic characteristics of Merbau wood. Merbau wood powder exhibits high moisture sensitivity, irregular particle sizes, and organic properties that accelerate mold formation, making conventional quality control approaches less effective. Therefore, this study offers novelty by integrating Six Sigma DMAIC and FMEA specifically in the context of Merbau wood powder waste processing. This research contributes scientifically by extending Six Sigma and FMEA application to bulk material waste industries and practically by providing data driven quality improvement strategies for CV. XYZ to reduce defect rates, enhance raw material consistency, and improve industrial competitiveness.

Research Methods

Data Collection

Data collection was conducted through observation and direct interviews with the head of operations and two workers at CV. XYZ. The required data included wood powder product defect data over one year (June to December 2024 and January to May 2025). The methods used were Six Sigma and FMEA. The stages in this research utilized DMAIC (Define, Measure, Analyze, Improve, Control), which is a systematic cycle for improving Six Sigma quality.

The respondents involved in this study consisted of the head of operations and two experienced production workers at CV. XYZ. These respondents were selected due to their direct involvement in daily wood powder processing activities and their in depth understanding of operational procedures and defect characteristics. The head of operations possesses managerial oversight and technical knowledge, while the workers contribute practical field experience. To minimize judgment bias in assigning Severity (S), Occurrence (O), and Detection (D) values, scoring was conducted through group discussions and consensus among respondents. Additionally, cross verification was performed by comparing interview results with direct field observations.

Define

The Define step establishes the problem definition and the objectives of the implemented Six Sigma project. The goal is to identify the products or procedures to be improved and establish them as Critical to Quality (CTQ) parameters [11]. In the context of the wood industry, identifying physical defects such as non-conforming dimensions and excessive moisture content becomes a critical CTQ parameter [12], [13]. .

Measure

The Measure step involves measuring the proportion of defective products to ensure that the defects do not exceed the required limits. This is done through the DPMO (Defect Per Million Opportunities) value and the Sigma Level to measure the company's baseline performance [14].

In this study, defect quantities were measured in kilograms rather than discrete units because wood powder is categorized as a bulk and continuous material. Measuring defects by weight provides a more accurate representation of material loss and quality deviation. Therefore, the DPMO calculation was adapted to reflect weight based defect opportunities, which remains valid for evaluating process capability in bulk material industries. The formulas for calculating DPMO and Sigma are as follows [15]:

$$DPMO = \frac{Total\ defects}{Total\ Production\ x\ Total\ CTQ}\, x\ 1.000.000 \quad [1]$$

$$Sigma\ Level = NORMSINV\left(1 - \frac{DPMO}{1.000.000}\right) + 1,5 \quad [2]$$

The total CTQ value was set at three for all observation periods because the same three critical defect types were consistently analyzed each month.

Analyze

The Analyze step determines the factors triggering product defects using a cause-and-effect diagram (Fishbone Diagram). This root cause analysis approach aligns with studies on complex industrial processes such as pharmaceuticals [16] and pump manufacturing [17], which emphasize the importance of visually mapping main causal variables (Man, Machine, Material, Method, Environment) before implementing improvements.

Improve

The Improve step determines the priority causes of defects with the highest values using the RPN (Risk Priority Number) calculation in the FMEA (Failure Mode and Effect Analysis) method. This methodology is supported by findings in systematic literature reviews [18] and ISO 9001 integration case studies [19], which show a positive correlation between prioritizing high RPN handling and a significant reduction in product defect rates.

Control

The Control step focuses on implementing improvement actions derived from defect factors with the highest Risk Priority Number (RPN) values to reduce the occurrence of product defects. In addition, rapid control methods for physical wood parameters, such as the use of handheld Near-Infrared (NIR) instruments, can be adopted to ensure consistent raw material quality in field operations [20], [21].

Results and Discussion

Define

This stage determines the object and purpose for improvement on wood powder. By knowing the number of defects and the percentage of defects, the CTQ can be determined for each type of defect. The following are the types of wood powder defects based on the highest total number of defects: powder mixed with other sizes (27,142 kg), wet powder (25,522 kg), and foul-smelling and moldy powder (10,165 kg).

Table 1. Product data and wood powder defect types (June 2024 - May 2025)

Periode	Production qty (kg)	Defect types			Total defective products (kg)
		Powder mixed w/ other sizes	Smelly & moldy powder	Wet powder	
June	35.500	3.560	420	360	4.340
July	36.550	4.230	600	340	5.170
August	40.000	4.500	780	450	5.730
September	50.000	1.200	1.425	3.580	6.205
October	49.500	1.260	1.260	2.650	5.170
November	49.600	1.230	1.300	2.760	5.290
December	49.750	2.010	1.260	3.260	6.530
January	52.600	2.150	800	3.520	6.470
February	52.750	2.160	760	2.375	5.295
March	40.000	2.010	620	2.200	4.830
April	35.620	1.522	510	2.035	4.067
May	28.566	1.310	430	1.992	3.732
Total	**520.436**	**27.142**	**10.165**	**25.522**	**62.829**

This stage is conducted to identify potential sources that can cause product defects and define CTQ, which serves as a constraint on product defect criteria.

Table 2. Critical to quality (CTQ)

No	Critical to quality (CTQ)	Description
1.	Powder Mixed with Other Sizes	Wood powder sizes do not comply with company SOPs; large, medium, and small sizes are mixed.

2.	Foul-Smelling and Moldy Powder	Rotten odor appears, and various types of molds grow on the powder in the storage area.
3.	Wet Powder	Powder is watery and mushy when moved to the storage area.

The identification of Critical to Quality (CTQ) parameters was based on defect frequency analysis using Pareto principles. Defect types with the highest cumulative defect weight were prioritized as CTQs. The three selected CTQs were validated through interviews with operational personnel to ensure their direct impact on downstream production quality. These CTQs significantly influence material usability in pallet and briquette manufacturing, where uniform particle size and controlled moisture content are essential.

Table 3. Defect percentage

Defect Type	Total Defective Products	Percentage (%)	Defect Type
Powder Mixed with Other Sizes	27,142	43.2%	Powder Mixed with Other Sizes
Foul-Smelling and Moldy Powder	10,165	16.2%	Foul-Smelling and Moldy Wood Powder
Wet Powder	25,522	40.6%	Wet Powder
Total	**62,829**	**100%**	**Total**

From the table above, it is shown that there are three types of defects with the highest percentage of defect rates: powder mixed with other sizes at 43.2%, wet powder at 40.6%, and foul-smelling and moldy powder at 16.2%.

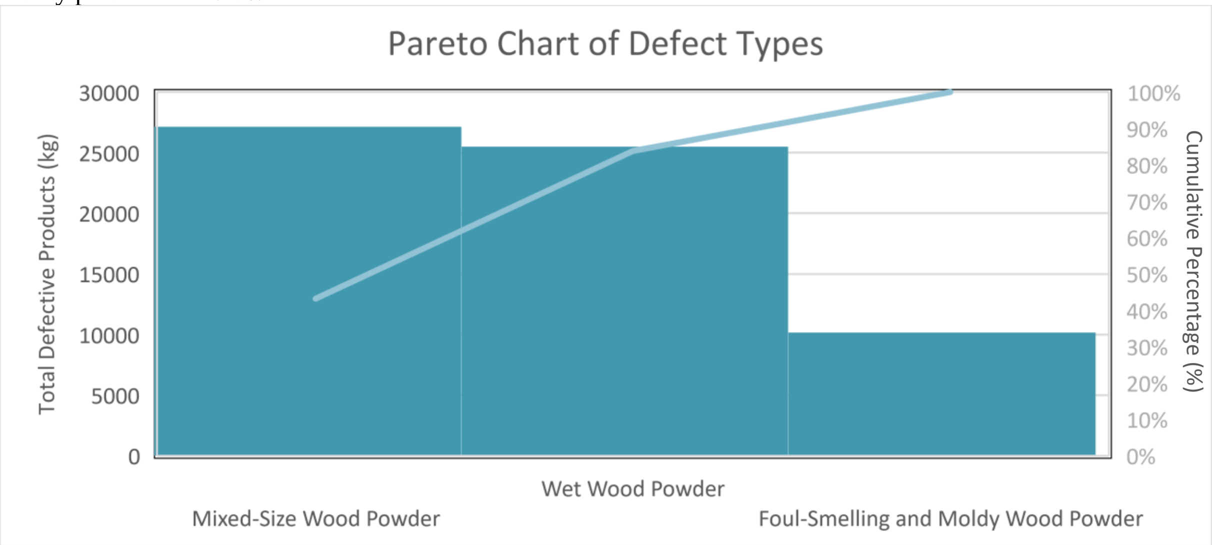

Figure 1. Pareto chart of defective product

Measure

This stage involves measuring the DPMO and Sigma values of the wood powder. The calculation is as follows (Example for June 2024):

$$DPMO = \frac{4.340}{35.500 \ x \ 3} x \ 1.000.000 = 40.751$$

$$Nilai \ Sigma = Normsinv\left(1 - \frac{40.751}{1.000.000}\right) + \ 1{,}5 = 2{,}46$$

Table 4. Calculation of dpmo and sigma values

Period	Production qty (kg)	Total defects (kg)	Total ctq	Dpmo value	Sigma value
June	35.500	4.340	3	40.751	2,46
July	36.550	5.170	3	47.150	2,45
August	40.000	5.730	3	47.750	2,45
September	50.000	6.205	3	41.367	2,46

October	49.500	5.170	3	34.815	2,47
November	49.600	5.290	3	35.551	2,46
December	49.750	6.530	3	43.752	2,46
January	52.600	6.470	3	41.001	2,46
February	52.750	5.295	3	33.460	2,47
March	40.000	4.830	3	40.250	2,46
April	35.620	4.067	3	38.059	2,46
May	28.566	3.732	3	43.548	2,46
Total	**520.436**	**62.829**	**36**	**487.454**	**30**
Average	**43.370**	**5.236**	**3**	**40.621**	**2,46**

The table above indicates that the average DPMO value for wood powder over the one-year observation period was 40,621 per million opportunities, with an average Sigma level of 2.46. These results indicate that continuous improvement efforts are required to enhance overall process capability.

Analyze

Based on defect identification using the Pareto diagram and the evaluation of DPMO and Sigma values in the Define stage, a Fishbone diagram was employed in the subsequent Analyze stage to determine the root causes of wood powder defects. The Pareto analysis shows that the dominant defect type was mixed size wood powder, accounting for 27,142 kg or 43.2% of the total defects.

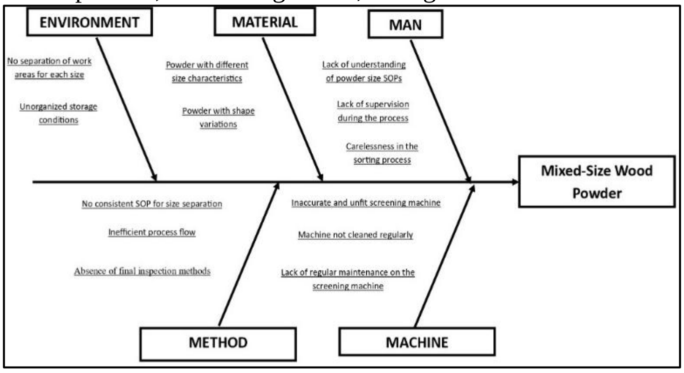

Figure 2. Fishbone Diagram of wood powder

Root Causes (Fishbone Analysis):

1. Environment: No separation of work areas for each size; unorganized storage conditions.
2. Material: Powder has different size characteristics; powder has shape variations.
3. Man: Does not understand the SOP for powder sizes; lack of supervision during the process; carelessness in the sorting process.
4. Method: No consistent SOP in size separation; inefficient process flow; absence of final inspection methods.
5. Machine: Screening machine is inaccurate and unfit for use; machine is not cleaned regularly; lack of regular maintenance on the screening machine.

The Fishbone analysis indicates that machine-related factors represent systemic issues, while human-related factors are primarily operational errors. Field observations revealed that inaccurate screening machines directly contributed to inconsistent particle sizes, which were further exacerbated by high moisture conditions in the storage area. The interaction between machine performance and environmental humidity increases the likelihood of wet and mixed-size powder defects.

Improve

This stage analyzes the primary causes of mixed-size wood powder defects using the Failure Mode and Effect Analysis (FMEA) method. FMEA prioritizes improvement actions by identifying failure modes with the highest Risk Priority Number (RPN), calculated as the product of Severity (S), Occurrence (O), and Detection (D). The assessment of S, O, and D values was conducted through consensus among the head of operations and two experienced production workers at CV. XYZ, who possess direct operational knowledge of wood powder processing conditions.

Table 5. FMEA Analysis

Defect	Factor	Cause of defect	S	O	D	RPN	RPN total
Wood powder	Man	Does not understand SOP for powder sizes	5	4	4	80	300

mixed with other sizes		Lack of supervision during the process	5	4	5	100	
		Carelessness in the sorting process	5	4	6	120	
	Material	Powder has different size characteristics	6	5	4	120	240
		Powder has shape variations	5	6	4	120	
	Machine	Screening machine is inaccurate and unfit	6	5	5	150	540
		Machine is not cleaned regularly	6	6	5	180	
		Lack of regular maintenance on the screening machine	7	6	5	210	
	Method	No consistent SOP in size separation	6	5	4	120	318
		Inefficient process flow	4	4	3	48	
		Absence of final inspection methods	5	6	5	150	
	Environment	No separation of work areas	6	5	5	150	300
		Unorganized storage conditions	6	5	5	150	

Highest Total RPN (Machine): 540.

The Severity (S), Occurrence (O), and Detection (D) values were assessed using a scale of 1–10, where higher values indicate greater impact, higher frequency, and lower detectability. Scoring criteria were determined based on operational risk severity, defect recurrence frequency, and existing detection controls. Machine-related factors obtained the highest RPN values due to their direct and continuous influence on defect generation, particularly inaccurate screening, and lack of preventive maintenance.

Control

This is the final stage in DMAIC to improve product quality. This stage determines improvement suggestions from the defect cause factors with the highest RPN, which is the first priority for improvement, namely the machine factor with an RPN value of 540.

Table 6. Improvement suggestion

Defect	Factor	Cause of defect	Improvement suggestion
Wood powder mixed with other sizes	Machine	Screening machine is inaccurate and unfit	Perform regular recalibration to ensure accuracy; if it is no longer fit, consider replacing it with a new screening machine according to SOP.
		Machine is not cleaned regularly	Establish a routine cleaning schedule for the screening machine and ensure all parts of the machine are thoroughly cleaned.
		Lack of regular maintenance on the screening machine	Create a planned preventive maintenance program for the screening machine covering component inspection, spare part replacement, and involving trained technicians.

Improvement implementation is recommended to be conducted over a three-month period, starting with machine recalibration in the first month, followed by routine cleaning schedules and preventive maintenance programs. Cost–benefit considerations indicate that preventive maintenance costs are significantly lower than losses caused by defective products. Monitoring should be conducted using inspection logs and control charts, with key performance indicators (KPIs) such as reducing mixed-size powder defects by at least 20% within three months.

Conclusion

Based on the research findings, mixed-size wood powder was identified as the dominant defect, accounting for 27,142 kg or 43.2% of the total defects. The average DPMO value for the observation period from June to December 2024 and January to May 2025 was 40,621 per million opportunities, corresponding to an average Sigma level of 2.46, indicating that continuous improvement efforts are required to enhance process capability. Fishbone and FMEA analyses revealed that machine-related factors represent the highest improvement priority, with a total RPN value of 540. The proposed improvement actions include machine recalibration, evaluation of machine replacement in accordance with SOPs, implementation of routine cleaning schedules, and establishment of preventive maintenance programs. These measures are expected to reduce defect occurrence and support consistent quality control under company supervision.

These findings are consistent with previous studies on waste reduction and productivity improvement [22] as well as the application of intelligent systems for wood surface quality control [23]. Furthermore, the adoption of integrated Lean and Six Sigma frameworks has been shown to enhance sustainable manufacturing competitiveness [24], [25].

This study contributes theoretically by extending the application of Six Sigma DMAIC and FMEA methods to the wood powder waste processing industry, which has received limited scholarly attention. Practically, the findings provide managerial insights for improving quality control systems in raw material waste processing companies. This research is limited by the number of respondents and potential seasonal variations in wood moisture content. Future studies are recommended to incorporate larger datasets, sensor-based moisture monitoring, and comparative analysis across different wood types.

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