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Quality Control Analysis of Painting Results in Steel Construction Projects Using Statistical Quality Control Methods and Failure Mode Effect Analysis at PT. BSB

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ABSTRACT

PT BSB is a company engaged in construction specialising in steel fabrication. There are various projects carried out at the company, namely bridges, steel structures, buildings, towers, and others. The research was conducted to analyse the quality of results in the painting process at PT BSB using statistical quality control (SQC) and failure mode effect analysis (FMEA) methods. Data collection is done by collecting primary and secondary data used in this study. The four types of painting defects obtained from the research results are Sagging/Runs, Orange Peel, Pin Hole and Seeds/Dirt. Based on the FMEA method, the level of defects can be determined based on the cumulative percentage value produced, where the highest defect value is 1750 Sagging/Runs defects. One of the factors causing the defect is the uneven spraying of paint, causing a layer of paint that is too thick, resulting in excessive accumulation of paint in certain parts that flow vertically and unevenly. From this research, it can be concluded that the company must use the SQC method to determine the causes of defects in the painting process and analyse improvements that must be prioritised.

Keywords: *Failure Mode Effect Analysis (FMEA), Painting Process Analysis, Statistical Quality Control (SQC)*

Introduction

Over time, the industry's development has taken place very quickly regarding science and technology. [1]. In this modern and increasingly competitive industrial era, all companies must be able to produce the quality of their products carefully. [2]. To be in a highly equivalent scope in world trade, companies must compete with each other to produce innovations from existing differences. [3]. Companies that can produce high-quality products with effective and efficient processes can excel in competing with the world trade industry. [4].

Service to customers by producing high-quality products can meet customer needs. [5]. In addition, it can also make cost expenditures lower and more economical because the resulting process can overcome or minimise the occurrence of a defect during the production process. [6].

The purpose of this research is to ensure that the products produced can meet predetermined specifications or conditions. Quality control is a comprehensive effort that involves careful observation, assessment, and supervision of a specific process to achieve the expected results. [7]. The success of quality control is critical because it acts as a critical element that determines an organisation's ability to achieve a competitive advantage in the business market. [8]. In every company, there is often a defect in every process, even in the field of steel construction. [9]. Where every work done will have the same quality characteristics, even if every incoming project has a different shape, but there are still similarities in factors such as quality in each process to be carried out, namely the cutting, assembly welding and painting processes. [10]. Of course, in each of these processes, there are many causes of defects, including operators' lack of focus and lack of machine maintenance, which ultimately cause failure [11]. To anticipate this, the company must carry out quality control so that the products produced can satisfy customers with the performance. [12]. Defects in the cutting process result from the absence of scratches from the steel. [13]. Defects in the welding process are the results of unqualified welding. [14]. Defects in painting are results that do not meet the requirements of the predetermined standards. [15].

PT BSB is a steel construction company that always works on large projects such as bridge construction, building construction, and others. The characteristics of its paint quality are considered quality. However, every time we work on a project, PT BSB always faces challenges by producing a product that is feasible to submit to the customer with a previous agreement. This can be seen from the painting process that has not been maximised, so many defects have not been resolved. That painting is one method to prevent corrosion, which often occurs in products made with iron-type raw materials [16]. But in fact there are still many painting defects such as sagging/runs, orange peel, pin holes and seeds/dirt that are still found and that cause the final result to not be maximized. The following are the results of data obtained by researchers from the Head of QC of the Painting Department, namely the results obtained are the production process at PT BSB along with data on the results of the number of defective products that occurred in the period April 2023 to March 2024. The following data can be seen in **Figure 1.**

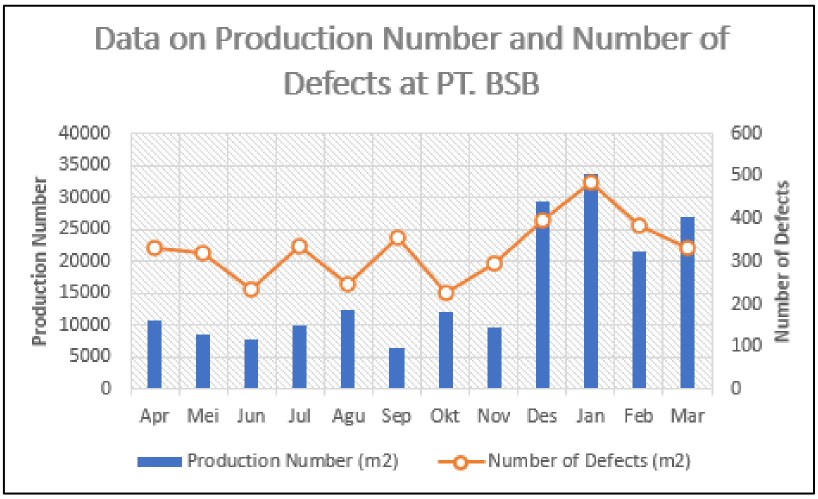

Figure 1 Data on Production Number and Number of Defect at PT. BSB

Figure 1 shows that from April 2023 to March 2024, the total production at PT BSB was 189457 m2, with a total occurrence of products that experienced production defects of 3946 m2. So PT BSB needs to implement quality control using Statistical Quality Control (SQC) to maintain the quality of its products. SQC is used to reduce failed products and maintain quality standards [17]. In addition, the Failure Mode and Effect Analysis (FMEA) method is used to determine the highest RPN value and propose improvements to the company. [18]. This research aims to control the results of painting quality and find effective quality control methods.

So, this study aims to observe the production process results that can determine the causes of defects and increase productivity. The methods used are statistical quality control and failure mode effect analysis.

Research Methods

The object of this research is focused on a steel construction company, PT BSB. In this research, the researcher took two methods to analyse the results of painting quality control: the SQC and FMEA. Data collection is carried out in this study by observing the results of output quality and interviews with the head of the QC department and the head of the painting department, who have the task of carrying out the process of supervision and checking at the stage of the steel construction painting process in the company. After the data is collected, the data processing and analysis are carried out using Statistical Quality Control (SQC) tools, such as a Checksheet, a document designed to record data or information. [19]. Stratification is the process or method of grouping data, populations, or other elements into appropriate categories based on specific characteristics or attributes. [20]. Histogram is a representation of the frequency distribution of data [21]. A scatter diagram, or scatterplot, represents the potential relationship or correlation between two quantitative variables. [22]. A control Chart is a statistical tool used to monitor changes in a process over time. [23]. Pareto Diagram is a graphical representation of data that illustrates the relative distribution of several different elements. [24]. And Fishbone Diagram, which is a graphical representation that shows the causal relationship between one or more variables [25]. Then, in the identification process, the amount of Risk Priority Number (RPN) is determined using the Failure Mode Effect Analysis (FMEA) method. [26].

Results and Discussion

After observing the problems in the field, the next step is for researchers to examine the implementation of quality control results using seven quality control tools. These seven tools discussed in this study are Check sheet, Stratification, Histogram, Scatter Diagram, Control Chart, Pareto Diagram and Fishbone Diagram. In addition, an FMEA analysis is carried out to determine the defects' results and corrective actions. FMEA analysis involves assessing factors such as probability of occurrence, detectability, and level of impact to determine the RPN value. These numbers are then used to recognise and prioritise the actions needed to reduce the detected risks. [27]. These criteria include aspects such as Severity, Occurrence, and Detection levels. The following can be seen in the table below:

Table 1 Guidelines for Severity Rating Values

Figure	Rating	Description
1 – 3	Low	Resulting in interruptions during the following procedure
4 – 6	Moderate	Resulting in unexpected maintenance or damage to equipment
7 – 8	High	Effect of failure of the previous process on the following process
9 – 10	Very High	Impact on safety

Table 2 Occurrence Rating Value Guidelines

Figure	Rating	Description
1	Small chance	Probability 1 in 10,000
2 – 5	Small possibility	Probability 1 in 1000
6 – 7	Medium possibility	Probability 1 in 20 to 1 in 200
8 – 9	Most likely	Probability 1 in 100 to 1 in 20
10	Very likely	Probability 1 in 10

Table 3 Detection Rating Value Guidelines

Figure	Rating	Description
1	Very high	The reliability of the detection approach is about 100%
2 – 5	High	The reliability of the detection approach is about 99.8%
6 – 8	Medium	The reliability of the detection approach is about 98%
9	Low	The reliability of the detection approach is about 90%
10	Very low	The reliability of the detection approach is about 90%

To determine the order of importance of a type of failure, the first step is to clarify the concept of Severity, Occurrence, and Detection levels, which are combined into a Risk Priority Number (RPN). The RPN calculation is done by multiplying the Severity, Occurrence, and Detection level values.

Checksheet

The results of data collection that can be seen from the results of the check sheet on building construction products are shown in the table below as follows:

Table 4 Data on The Number of Types of Defects

Year	Month	Production Quantity (m^2)	Defective				Number of Defective	Percentage
			Sagging/Runs	*Orange Peel*	*Pin Hole*	*Seeds/Dirt*		
2023	Apr	10806	130	90	70	70	360	8%
	Mei	8745	160	30	40	90	320	8%
	Jun	7843	100	50	20	30	200	6%
	Jul	9834	130	70	90	50	340	9%
	Agu	12456	110	40	20	30	200	6%
	Sep	6451	180	50	70	50	350	9%
	Oct	12212	140	20	50	20	230	6%
	Nov	9602	150	100	30	20	300	8%
	Des	29381	170	90	60	90	410	10%
2024	Jan	33714	220	120	50	100	490	12%
	Feb	21470	160	110	80	50	400	10%
	Mar	26943	100	70	90	80	340	8%
	Total	189457	1750	840	670	680	3940	

Table 4 is data from interviews with the Head of the QC Department which contains data on types of defective products from April 2023 to March 2024, namely 175 Sagging/Runs, 84 Orange Peel, 67 Pin Holes and 68 Seeds/Dirt. With a total production of 1343 and a total of 394 defective products. The overall results showed the most significant product defects, 175 Sagging/Runs, which must be prioritised.

Stratification

Data was collected through interviews with the Head of QC of the Painting Department regarding defect criteria and the number of paint defects. This stratification data is organised into groups according to criteria related to painting process failures. In the table below, a grouping is done according to the type of defect that occurs to make it easier to understand.

Table 5 Stratification of the Number of Types of Painting Damage

Defect Type	Product Defect Frequency (m^2)
Sagging/Runs	1750
Orange Peel	840
Seeds/Dirt	680
Pin Hole	670
Total	**3940**

From **Table 5,** it can be seen that the most significant number of defects is Sagging/Runs with a total number of defects of 1750, so the type of defect that must be prioritised is Sagging/Runs, so that there is no significant increase in defects, but not only the Sagging/Runs defect type. But all kinds of defects exist in every painting process. Implementing quality control through stratification can make identifying the most significant kinds of defects easier.

Histogram

Histogram creation is required to facilitate visualisation and understanding of the types of damage that occur according to the data in the check sheet table—building construction production data at PT. BSB is presented in a bar chart divided by type of damage. The following is a histogram for building construction at PT. Bangun Sarana Baja. Month April 2023 - March 2024:

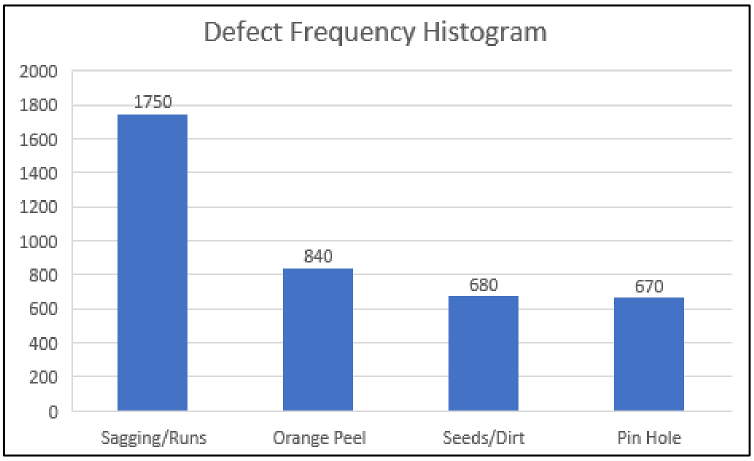

Figure 2 Defect Frequency

Figure 2 shows the histogram data for building construction production at PT. BSB before making repairs based on what was mentioned previously, we can see that the most common types of defects are Sagging/Runs with a total of 1750, Orange Peel with a total of 840, then Seeds/Dirt defects with a total of 680 and Pin Hole defects with a total of 670.

Diagram Scatter

The purpose of using this scatter diagram is for researchers to find the correlation between variables X and Y. Variable X shows the amount of production. In contrast, variable Y indicates the number of defects in production from April 2023 to March 2024.

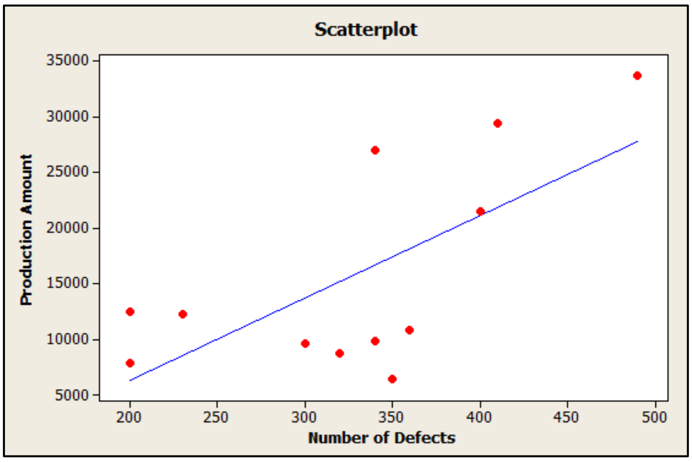

Figure 3 Scatterplot of Production Defects and Production Amount

In **Figure 3,** it can be concluded that PT. BSB shows a positive relationship between variable x (Number of Defects) and y (Production Amount). This means that as the production quantity increases, the probability of the number of defects also increases. It can be seen that variable X and variable Y show a connected pattern.

Control Chart

Control charts are statistical instruments used in quality management to continuously monitor processes and identify changes or deviations from expected conditions. Its primary focus is ensuring that the process remains within appropriate statistical control, meaning variations are caused by joint, familiar factors rather than unexpected, specific ones.

Table 6 Number of Defects

Sample	Number of Defects
1	360
2	320
3	200
4	340
5	200
6	350
7	230
8	300
9	410
10	490
11	400
12	340
Grand Total Defects: 3940	

From **Table 6**, the researcher processed the Control Chart data using the C control chart formula with the help of Microsoft Software, so the results obtained were:

Table 7 Control limit calculation results for April 2023-March 2024

Sample	Many Defective Products	CL	UCL	LCL
1	360	328	382,69	273,97
2	320	328	382,69	273,97
3	200	328	382,69	273,97
4	340	328	382,69	273,97
5	200	328	382,69	273,97
6	350	328	382,69	273,97
7	230	328	382,69	273,97
8	300	328	382,69	273,97
9	410	328	382,69	273,97
10	490	328	382,69	273,97

11	400	328	382,69	273,97
12	340	328	382,69	273,97
Total	**3940**			

From **Table 7** of the data above, the Control Map C data processing results can be compiled as an image of Control Map C using Microsoft Excel software. So Control Map C can be seen in **Figure 4** :

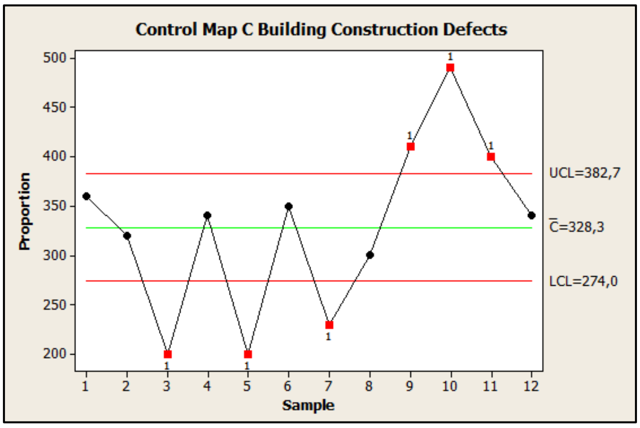

Figure 4 Control Map C Building Construction Defects

From **Figure 4** C Chart, there is Out of Control data, namely data 3, 5 and 7 are outside lower control (LCL) and data 9, 10 and 11 are outside upper control (UCL)

Diagram Pareto

A Pareto diagram is a graph used to identify, categorise, and reduce product defects. This graph helps to see which defects are most significant in production results. The table below is a table of the kinds of defects and the number of defects during the period April 2023 - March 2024 in the production of building construction PT. BSB :

Table 8 Frequency of Building Construction Production Defects

Type of Damage	Defect Frequency	Cumulative Frequency	Percentage of Defects	Cumulative Percentage
Sagging/Runs	1750	1750	44%	44%
Orange Peel	840	2590	21%	66%
Seeds/Dirt	680	3270	17%	83%
Pin Hole	670	3940	17%	100%

Based on **Table 8**, then create a Pareto Diagram. **Figure 5** is a Pareto Diagram created based on the table above.

Figure 5 shows the types of defects that often occur in building construction production at PT. BSB from April 2023 to March 2024 is Sagging/Runs with a percentage of 44%, and the total frequency is 1750 Sets; of the most significant number of defects, this is the most critical problem and must be prioritised. It is recommended to analyse the level of defects using a Fishbone Diagram.

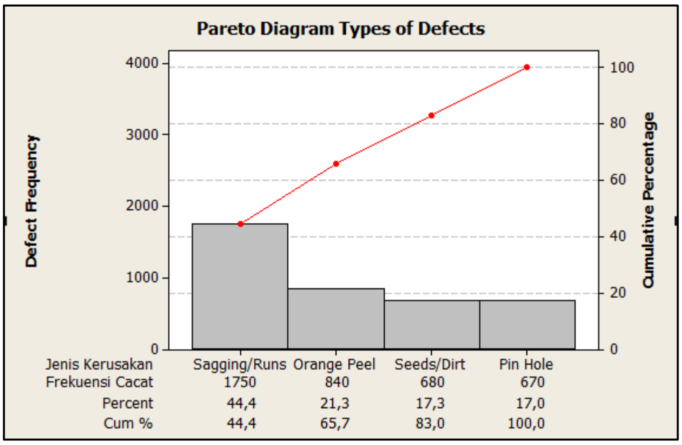

Figure 5 Pareto Diagram of Types of Defects

Diagram Fishbone

Fishbone diagrams, often called fishbone diagrams, are used to analyse the factors that cause product defects. Factors that affect the product and cause defects in general.

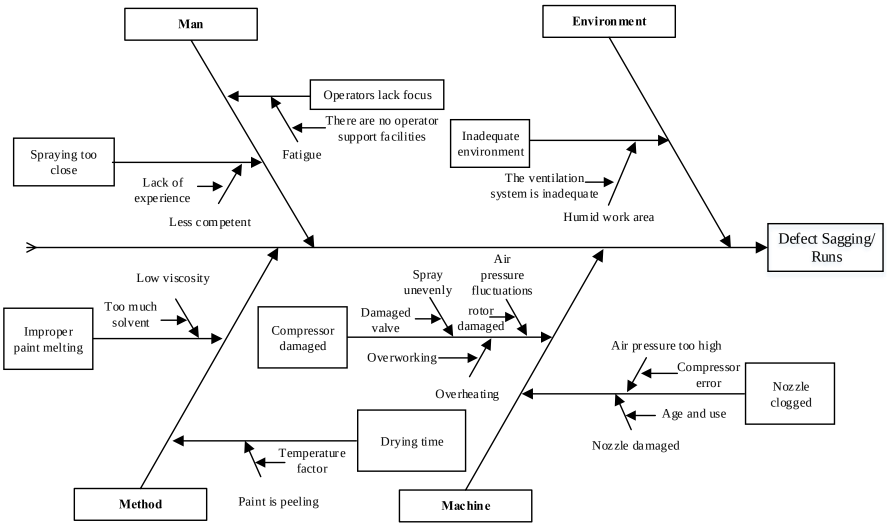

Figure 6 Fishbone Diagram

From **Figure 6** Sagging/Runs defects above, 4 main factors cause Sagging/Runs defects. This Fishbone Diagram shows the causes of production defects in painting building structures at PT. BSB.

Failure Mode Effect Analysis (FMEA)

FMEA is a structured approach applied in engineering and risk management to recognise and assess potential failures in a product, process or system and their implications for users or the environment. Through FMEA, teams can examine possible failure modes, their causal factors, and their impacts while identifying preventive or corrective measures that can be taken to reduce the risk of failure.

Table 9 RPN Value Calculation

Factor	Failure Mode	S	Causes of Failure	O	Failure Effect	Control	D	RPN	Rank
Man	Wrong nozzle setting	7	Lack of Training	5	The painting process is not up to standard and suffers from many defect factors	Training to improve skills in applying paint techniques,	5	175	2
	Lack of supervision	3	Operator fatigue	4	A lot of dust and dirt are still attached	then requiring stricter supervision during the	5	60	7

Factor	Failure Mode	S	Causes of Failure	O	Failure Effect	Control	D	RPN	Rank
					because it has not been cleaned.	painting process and not overloading workers, to make operators more focused.			
Machine	Broken nozzle	6	Clogged nozzles	6	It may cause unpredictable air pressure, jeopardizing the operator's safety.	Perform regular preventive maintenance on equipment and machinery, including periodic cleaning and maintenance to prevent undesirable events	4	144	4
	Overloading the compressor used	9	Unstable air pressure	7	Resulting in a decrease in finishing quality, with a less smooth or uneven finish. This may affect the final result.		4	252	1
Method	Inappropriate paint material mixture	7	Improper paint mixing or melting	6	Improperly mixed paint may not provide optimal protection or durability against ambient temperatures or conditions in use.	Ensure operators follow proper mixing procedures according to the paint manufacturer's instructions.	4	168	3
	Inappropriate temperature and humidity	3	Too short drying time	7	It creates optimal adhesion to the painted surface, possibly resulting in paint peeling off.	Control the temperature and humidity of the air around the painting area to ensure optimal environmental conditions for paint drying.	4	84	6
environment	Unstable temperature	3	Inadequate environment	5	Resulting in a decrease in the finishing quality of the paint layer	Increase ventilation in the drying process area	6	90	5

The RPN calculation process involves discussions with the company. The findings that have been analysed are a severe problem that must be addressed immediately because this could negatively impact the future. After investigating and evaluating the RPN value, the next step is to develop a comprehensive improvement plan to find various weaknesses. Errors with the most significant RPN values will be prioritised, and recommendations for improvement will be provided to reduce the occurrence of failures. The proposed improvements are shown in **Table 10**.

Table 10 Proposed Improvements

Impact of failure	RPN Value	Remedial solution
Unstable air pressure	252	• Installing a pressure regulator • Air pressure monitoring • Performing routine maintenance • Using backup equipment • Adjusting the process when painting

The table above shows the highest RPN value with a total of 252. To reduce the occurrence of these failures, improvements need to be made to the highest RPN value. The proposed improvements mentioned above come from researchers' insights and PT employees' opinions. BSB is also the same person who proposes solutions for these improvements. So, this must be a top priority, and improvements must be made immediately.

Conclusion

The research results show that the Sagging/Runs defect is too often at the highest level of disability rate compared to other types of defects. What causes defects occur due to human factors, machines, methods and the environment, but what often happens when Sagging/Running defects appear is because of human factors, namely unstable air pressure, which ultimately causes the paint to accumulate at one point and finally, the paint layer decreases. The Sagging/runs defect type has a high proportion rate, namely 44%. Of all the types of defects identified, the Sagging/Runs defect has the most significant number. In contrast, the other defects do not reach the level of disability reached by the Sagging/Runs defect. By referring to the results of this analysis, which was carried out using the FMEA method, the measurement factor shows the highest RPN value with an RPN value of 252, so the solution for improving unstable air pressure must be a top priority for the company to immediately find a solution and make improvements so that Sagging/Runs defect levels do not increase during the painting process.

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