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Analysis of the Application of the Six Sigma Method in Quality Control of Floating Equipment Products (Case Study: Manufacturing Industry)

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A B S T R A C T

The company engaged in manufacturing with a focus on producing oilfield equipment used for drilling exploration wells, especially the cementing process. One of the tools produced is floating equipment. To identify and maintain the quality of floating equipment products, the Six Sigma and Kaizen 5W1H methods are used. At the define stage, it is determined that the problems that occurred during the 2023 period with a total production of 923 units and 90 units of defects, there are 5 types of defects in the form of, non-conforming cement test results, unmatch components, damaged materials, non-conforming sizes, and non-conforming thread profiles, based on CTQ and Pareto diagrams, the main priority for improvement is the type of defects in non-conforming cement test results, unmatch components, and damaged materials. At the measure stage, the DPMO (defect per million opportunity) calculation is 19,501.625 with a sigma level of 3.5642, this value shows that improvements are still needed in the production process of floating equipment products. The proposed improvements focus on training production operators and overcoming human error, maintenance and inspection of machines and other tooling, increasing inspection and supervision and paying attention to the storage and treatment of the materials used.

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1. INTRODUCTION

Product quality is a characteristic related to a product's ability to meet customer needs and will influence customer satisfaction with that product (Novia et al., 2024).Satisfied customers will make repeat purchases in the future, leading to customer loyalty. Quality improvement is included in the production

process or is still in the production process or work in process (Okstevia & Sumiati, 2024).
In an effort to achieve success in providing customer satisfaction and competing in the market, companies make efforts to meet customer needs and desires, thereby creating customer loyalty. With this, companies can compete and survive in their industry. Many methods can be used to control quality, one of which is the Six Sigma method. This method is widely used as an effective quality control approach.

Six Sigma is a quality control method that improves quality by determining the sigma value in the production process. The goal of this method is to eliminate production defects, reduce manufacturing time, and minimize production costs to achieve a final product with minimal or no (Agrina, 2023). PT ABC is a company engaged in manufacturing, focusing on producing oilfield equipment used for exploration drilling, particularly in the cementing process. PT ABC manufactures oilfield equipment such as liner hangers, casing packers, floating equipment, and cementing equipment.

The high demand from various sectors of the oil industry in Indonesia and abroad requires the company to have a good production process to maintain product quality, especially for floating equipment. However, in reality, there are still products that experience defects and non-conformance, resulting in losses and waste for the company. Given these issues, the researcher aims to analyze and resolve these problems using the Six Sigma method and Kaizen improvements in the improvement phase.

2. LITERATURE REVIEW

According to (Priambodo et al., 2020), the cementing process is the pumping or pushing of a certain amount of cement slurry suspension that flows from below the casing up to the annulus between the casing and the formation.

According to (Kumrotin & Susanti, 2021), product quality serves to establish a good relationship with consumers, allowing them to have preferences and meet their needs with the product itself. The quality of a product, whether good or bad, can be assessed by the consumers themselves. According to (Muttaqin & Aryanny, 2024), quality is an important factor for a company in achieving customer satisfaction, whether in producing goods or services; therefore, quality improvements are necessary for the company. According to (Dwi et al., 2021), one of the influencing factors in purchase decisions is product quality, products with good quality that meet applicable standards will enhance sales reputation. According to (Walujo et al., 2020), quality is used as a competitive tool to ensure satisfaction or assurance for consumers. Quality serves as an indicator of success in engineering, good quality will have a positive impact in the form of increased profits. According to (Gaspersz, 2010), quality control is an operational activity conducted to meet expected quality standards. Quality control has several objectives as follows: (1) minimize errors and enhance quality, (2) inspire good teamwork, (3) encourage engagement in tasks, (4) increase employee motivation, (5) improve problem-solving skills, (6) foster attitudes toward problem-solving, (7) enhance communication and relationships between supervisors and employees, (8) develop consumer awareness, (9) cultivate leadership and improve employee performance, and (10) achieve cost savings.

Defective products are goods or services that have gone through the production process but have deficiencies, resulting in subpar quality and imperfection(Yusuf & Supriyadi, 2020). According to(Terang et al., 2023), damaged products are those that do not meet the applicable quality standards and cannot be economically repaired to become good products.

According to (Ahmad, 2019), Six Sigma is a structured method for system improvement that emphasizes minimizing process modifications and reducing defects in a product through the use of statistical data and appropriate problem - solving techniques. Six Sigma refers to the concept of zero defects, which pertains to failures. According to (Pande et al., 2002), Six Sigma is based on a strong understanding of customer needs, discipline with data facts and statistics, and a focus on managing, improving, and instilling business processes. According to

(Gaspersz, 2002), Six Sigma can control processes within an industry that focuses on consumers and emphasizes process capability. It is a comprehensive and adaptive system to achieve, maintain, and maximize business success. Six Sigma aims to improve quality with a target of 3.4 defects per million opportunities (DPMO). According to (Gaspersz, 2007), the five phases of Six Sigma are used to address specific problems with the following methodology: (1) Define; formally defining the goals for process improvement, (2) Measure; measuring the current performance of the process (baseline measurements) to allow comparison with the established targets, (3) Analyze; analyzing the cause-and-effect relationships of various factors studied to identify the dominant factors that need to be controlled, (4) Improve; optimizing processes using various analyses, (5) Control: controlling the process periodically to enhance process capability.

In the define phase, the process flow or general production flow is identified, followed by the SIPOC diagram (Supplier, Input, Process, Output, and Customer), which shows information related to raw materials, the production process flow, inputs required in production, the products produced, and the customers who purchase those products. The next step is to determine Critical to Quality (CTQ) aspects, which are the factors that need to be considered from customer desires to prevent complaints during the production process (Agustiandi et al., 2021)

According to (Faritsy & Syaifuddin, 2023), control charts are used to eliminate abnormal variations by separating those caused by special and common causes. Control charts are used to analyze the number of products that experience defects during the production process by calculating the proportion of defects and determining the center line, upper control limit, and lower control limit (Oktavia & Herwanto, 2021)

According to (Faritsy & Syaifuddin, 2023), a histogram is a graphical representation that functions to visually show the distribution of data. Histograms provide information about several data points in the process regarding variations and quantities, which can assist management in quality improvement and control. Histograms are used as a tool for presenting data that shows frequency distribution (Alfadilah et al., 2022)

According to (Faritsy & Syaifuddin, 2023), this diagram is also known as a fishbone diagram and serves to illustrate the main factors that influence quality and have consequences on a specific problem being studied. According (Paisal & Cahyana, 2020), the factors used in manufacturing companies include: (1) Method, (2) Material, (3) Machine, (4) Man, (5) Environment.

According to (Faritsy & Syaifuddin, 2023), Pareto diagram is a bar graph that shows problems based on the frequency of occurrences in sequential order. The order starts from the most frequently occurring issues on the left to the least occurring ones on the right. According to (Tajuddin & Junaedi, 2021), the Pareto diagram allows for identifying the most dominant types of defects using the Pareto principle, which is the 80:20 rule, where 80% of defects are caused by 20% of the causes.

According to Sutrisno (2022) in (Yuliarty et al., 2024), Kaizen is an activity that can be performed in daily routines. Besides aiming to increase productivity, it also directs the proper execution of processes across all factors, from human involvement to methods. This approach can reduce workload, minimize waste, and make it easier for individuals to identify unnecessary activities. By avoiding production waste, product quality can also be improved. According to (Indrawansyah & Cahyana, 2019) the implementation tools for Kaizen consist of three tools: (1) Kaizen Five Step Plan. This tool is often referred to as the 5S method, which stands for the Japanese words: seiri, seiton, seiso, seiketsu, shitsuke. (2) 5-W and 1-H. This method is used as a management tool in various environments, consisting of 5-W: Who, What, Where, When, Why, and How. (3) Kaizen Five M Checklist. This tool focuses on five key factors involved in each process: man, machine, material, and method. Each aspect can be checked during every process.

The 5W + 1H concept, according Paramitha (2012) in (Amirudin & Dewi Masruroh, 2020), states that Kaizen is a questioning technique using basic questions: (a) What to ask what problem is occurring, (b) Who to identify who made the mistake, (c) Why to ask why the problem occurred, (d) Where to determine where the problem happened, (e) When to ask when the problem occurred, and, (f) How to inquire how the problem can be resolved to prevent it from happening again.

3. RESEARCH METHOD

In this research, the quality control problem is addressed using the Six Sigma method with the step as define, measure, analyze, and improve. this study does not carry out control and does not make comparisons between previous values and values after improvement, only limited to providing suggestions and the Kaizen 5W1H approach, with the steps illustrated in Figure 1.The research was conducted at PT ABC, and the first steps taken by the researcher included conducting a field survey, formulating the research problem, reviewing the literature, and establishing the research objectives. Following this, the data collection phase was carried out, using data on the production volume of floating equipment during the 2023 period and data on the number and types of defects in floating equipment products during the same period. Next, the Six Sigma methodology was applied, starting with the define stage, which involved identifying the research object, describing the Critical to Quality (CTQ), and creating a Pareto chart to prioritize improvements. The measure stage followed with the development of control charts, and the calculation of DPO (Defects Per Opportunity), DPMO (Defects Per Million Opportunities), and Sigma Quality Level. The next step was the analysis phase, which included an analysis of the DPMO and Sigma Quality Level values, as well as an analysis of the factors causing defects using a cause-and-effect diagram. The fourth stage was the improve phase, where improvement analysis was conducted using the Kaizen 5W1H method. In this study, the process only progressed to the improve stage, limited to providing improvement recommendations.

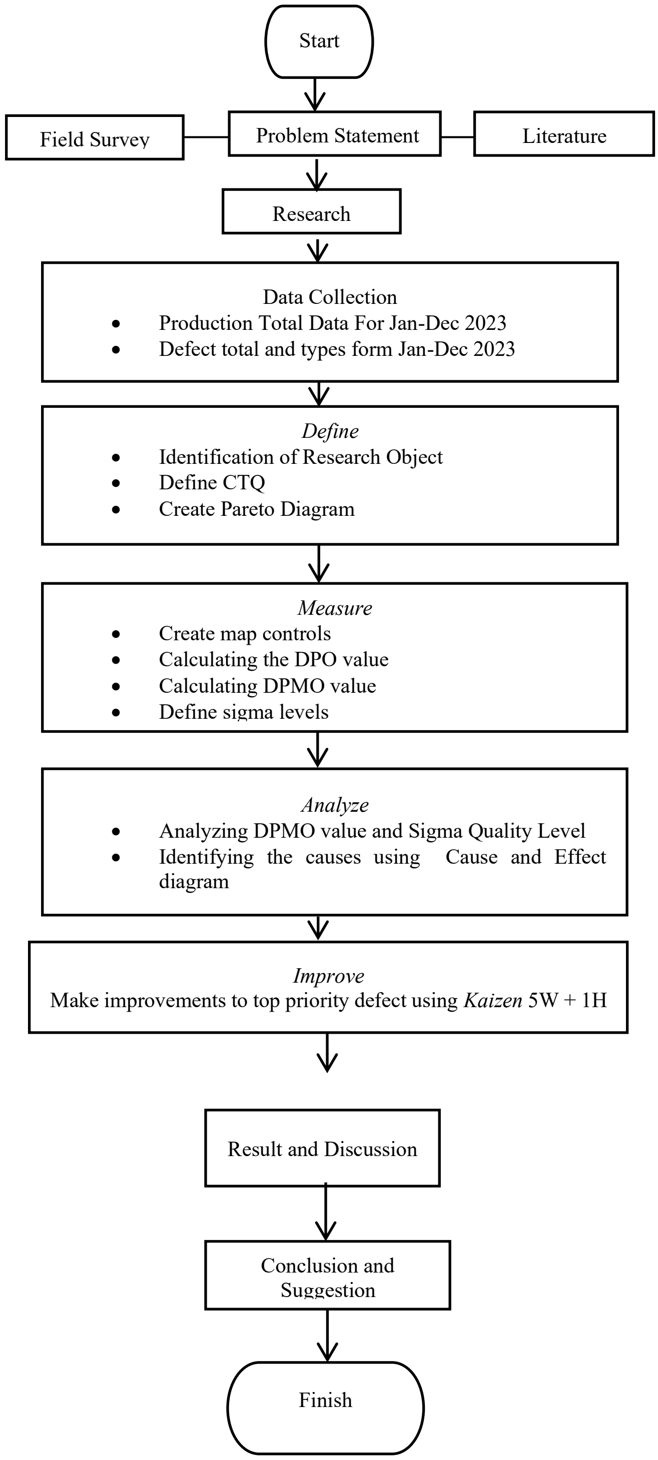

Figure 1. Research flow diagram

4. RESULT AND DISCUSSION

The problem faced by the company is defects in floating equipment products. This research will focus on discussing the defects that occur during the production process of floating equipment, identifying their root causes, and providing improvement suggestions that can enhance the quality of floating equipment products. The research process begins with identifying defects, calculating the DPMO value and Sigma Quality Level, identifying root causes using various factors with a cause and effect diagram, and providing improvement suggestions using the Kaizen 5W1H method, so that the company can consider ways to improve the level of product defects.

4.1 Define Stage

Table 1. Production data types and number of product defects 2023

Periode	Production Quantity	Number of Defects	Non-Conforming Cement Test Results	Unmatched Components	Damaged Material	Incorrect Size	Non-Conforming Thread Profile	%
January	99	2	0	0	0	2	0	2.02%
February	68	1	0	0	0	1	0	1.47%
March	29	11	0	10	0	1	0	37.93%
April	25	1	0	0	0	1	0	4.00%
May	84	4	0	0	0	3	1	4.76%
June	86	1	0	0	1	0	0	1.16%
July	64	0	0	0	0	0	0	0.00%
August	130	21	5	7	8	0	1	16.15%
September	103	6	1	0	3	2	0	5.83%
October	108	43	40	0	1	2	0	39.81%
November	67	0	0	0	0	0	0	0.00%
December	60	0	0	0	0	0	0	0.00%
Total	**923**	**90**	**46**	**17**	**13**	**12**	**2**	**9.75%**
Average	**76.92**	**7.50**	**3.83**	**1.42**	**1.08**	**1.00**	**0.17**	**1%**

Based on Table 1, the total production is 923 units, with 90 units found to be defective. In the production of floating equipment, there are several critical quality attributes that are essential to the customers purchasing these products, namely as follows (Table 2).

Table 2. Defects types

No	Type of Defect	Description
1	Non-Conforming Cement Test Results	The cement strength test results do not meet the standard of 550 KN or do not meet the requirements.
2	Unmatched Components	Components do not match or do not integrate well with other components during assembly.
3	Damaged Material	Material is damaged or cracked during machining or other processes.
4	Incorrect Size	Diameter/length does not meet the specified requirements or manufacturing drawing.
5	Non-Conforming Thread Profile	Thread profile does not meet the applicable standard specifications.

The number of each type of defect found in the production of floating equipment in 2023 can be seen in the histogram diagram below (Figure 2).

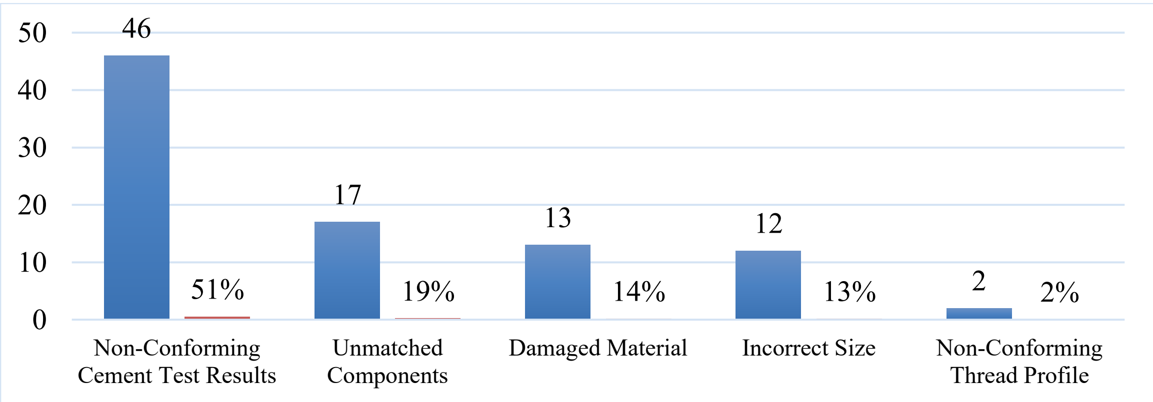

Figure 2. Histogram of defects

Based on the types of defects that have been identified, a prioritization calculation for improvements on these defects is conducted using the Pareto Diagram as follows (Figure 3).

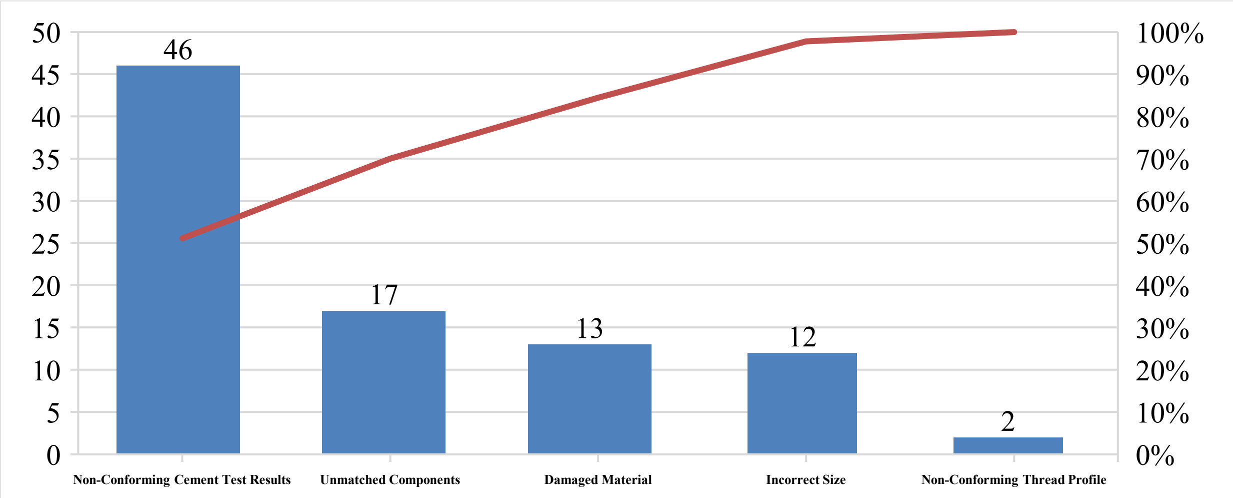

Figure 3. Pareto diagram of product defects

Based on the Pareto diagram that has been created, the types of defects that have the most significant impact and fall within the 80% category are defects related to non-compliant cement test results, unmatch components, and damaged materials, with a cumulative frequency reaching 84%. Therefore, the defects that need to be prioritized based on critical quality attributes and improvement priorities, as shown in the Pareto diagram, are non-compliant cement test results, unmatch components, and damaged materials.

4.2 Measure Stage

a. Control Chart

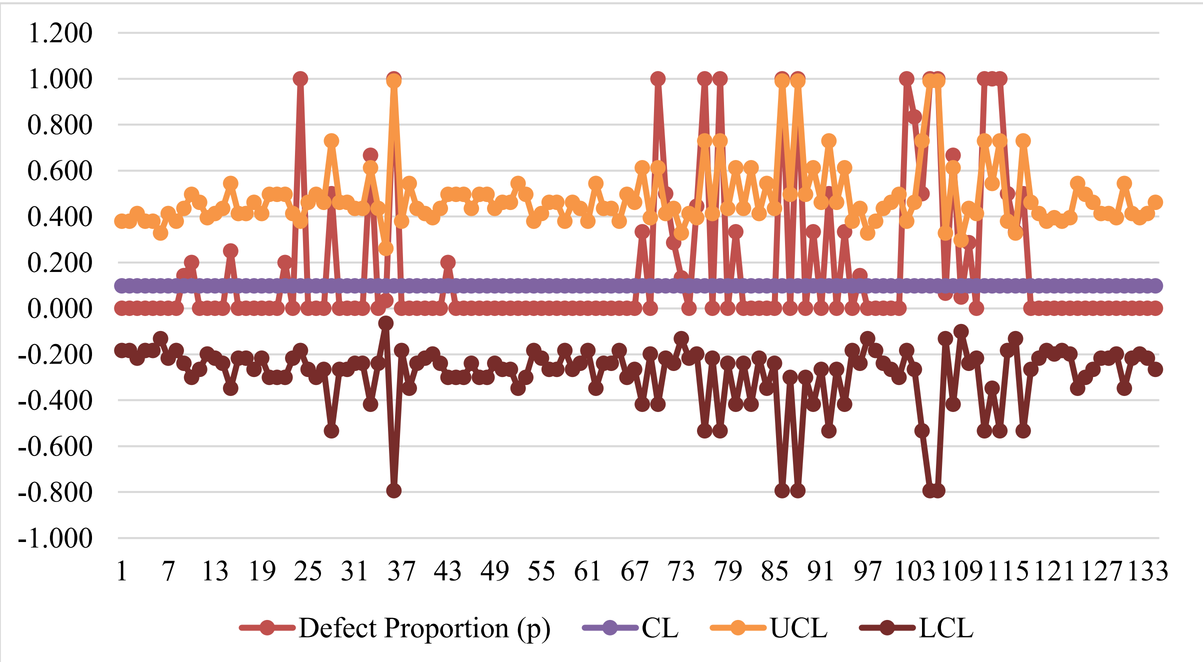

Figure 4. Overall control chart

In the control chart for all floating equipment products, it can be seen that there are still several production instances where the defect proportion exceeds the Upper Control Limit, specifically 20 production points: 10 points for non-compliant cement test results, 3 points for unmatch components, 5 points for damaged materials, and 2 points for size discrepancies.

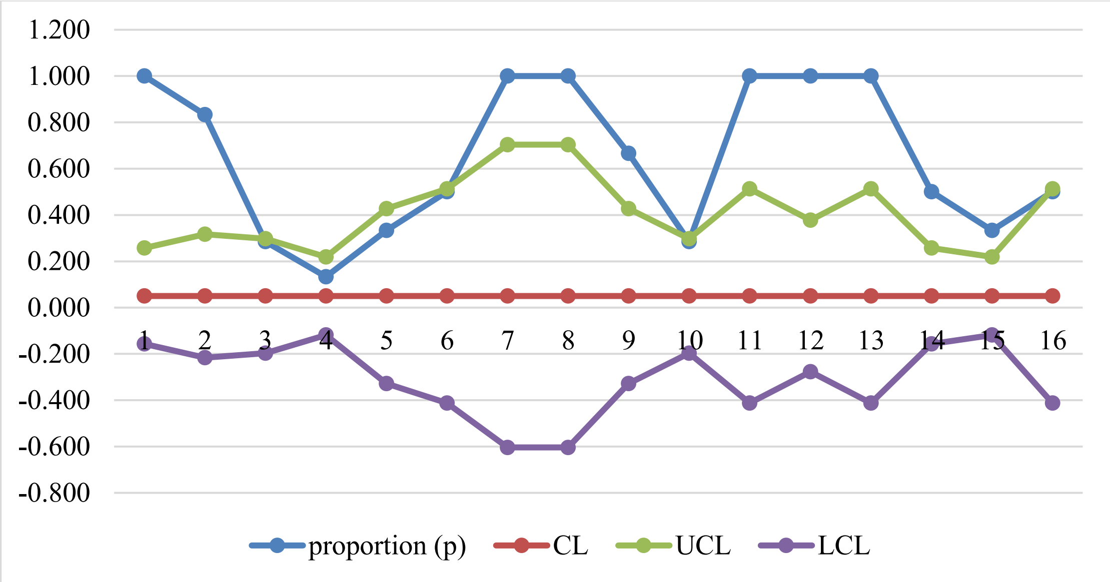

Figure 5. Control chart non-conforming cement test results

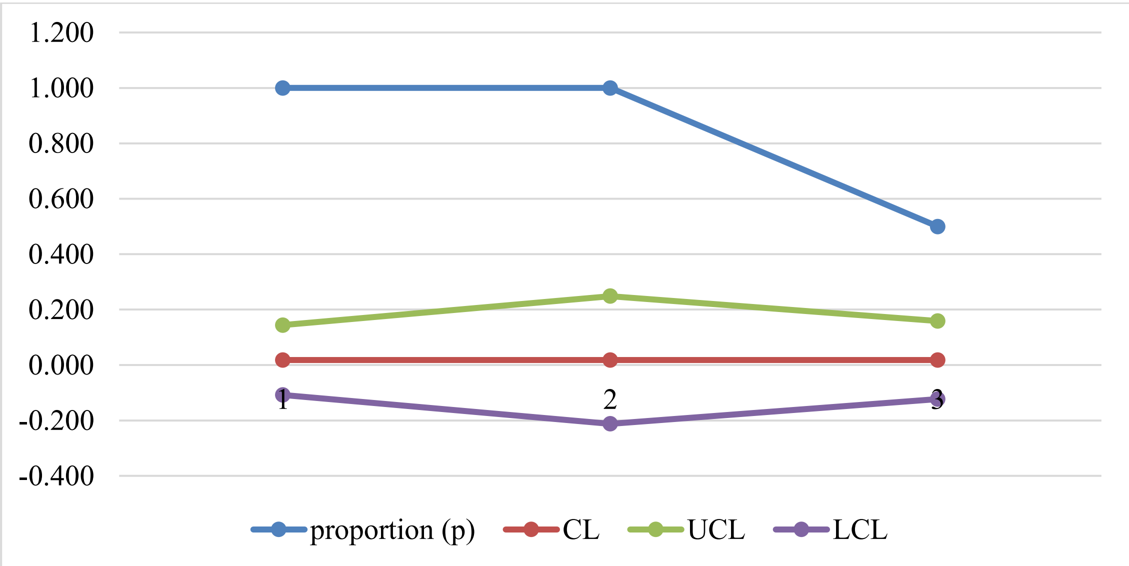

Figure 6. Control chart unmatched components

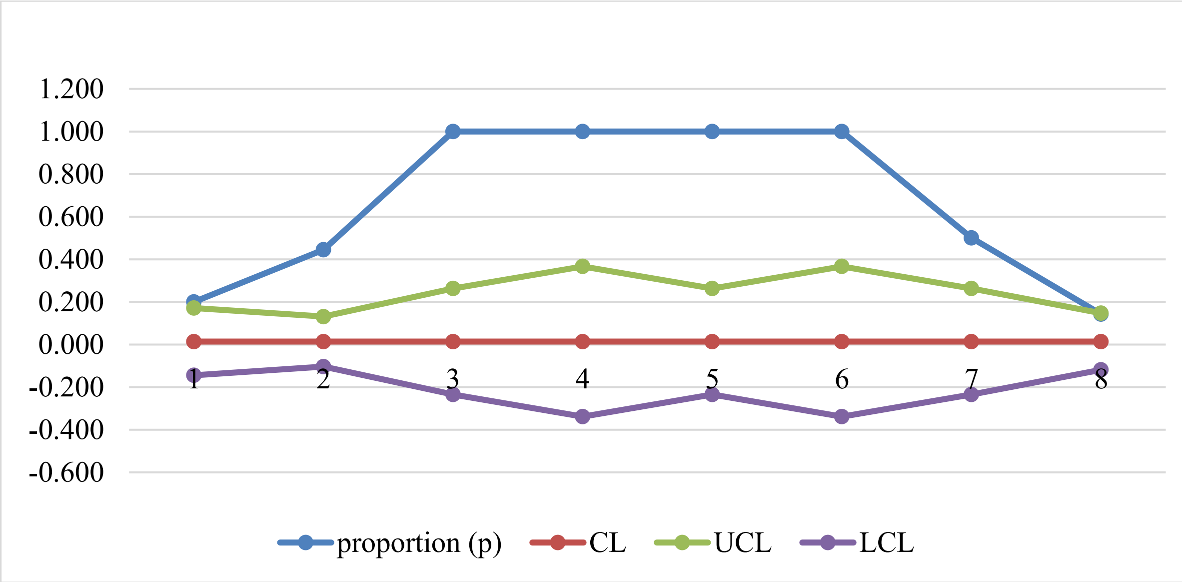

Figure 7. Control chart damaged material

Based on Figure 5, 6, and 7, it can be seen that there are still many data that are on the control limit. This shows that there are types of defects that are outside the control limits, so it is necessary to conduct an analysis to determine the cause of the defects.

b. Calculating DPO, DPMO, and SQL Value

$$DPO = \frac{\text{Total Defective Products}}{\text{Total Production x Potential CTQ}}$$

$$= \frac{90}{923 \text{ x } 5}$$

DPO = 0,0195

DPMO = DPO X 1.000.000

DPMO = 0,0195 X 1.000.000

DPMO = 19.501,625

Level Sigma = NORMSINV (1-(DPMO/1.000.000))+1,5

Level Sigma = NORMSINV (1-(19.501,625/1.000.000))+1,5

Level Sigma = 3,5642

The obtained sigma level is 3.5642. In the sigma level conversion table, this value falls within the 3-sigma level.

4.3 Analyze Stage

In the analysis stage, a cause-and-effect diagram or fishbone diagram is used to identify the factors causing the types of defects present.

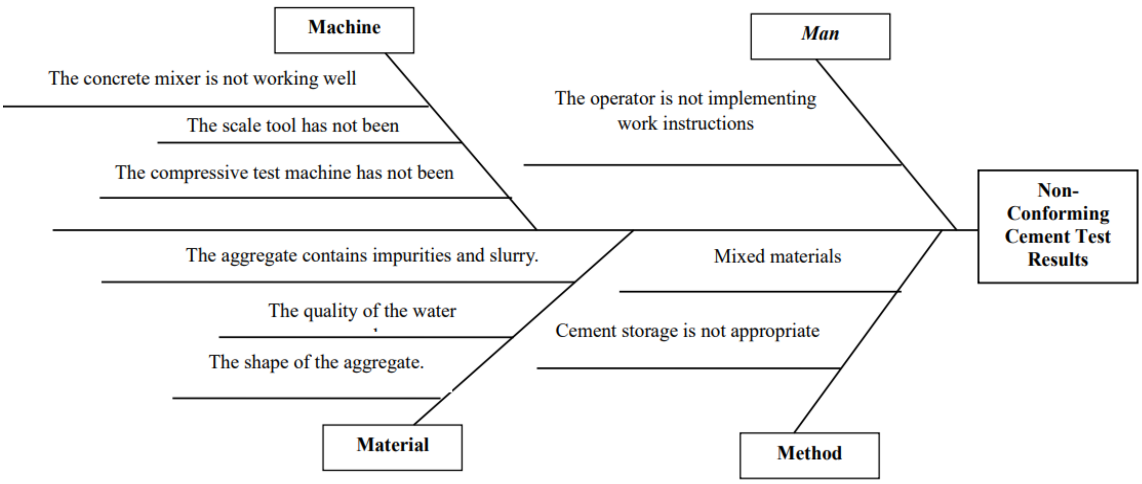

Figure 8. Fishbone diagram non-conforming cement test results

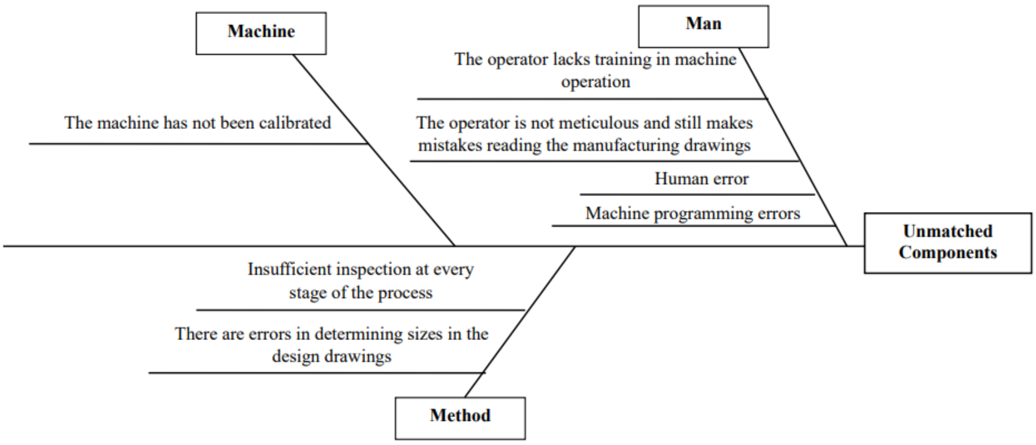

Figure 9. Fishbone diagram unmatched components

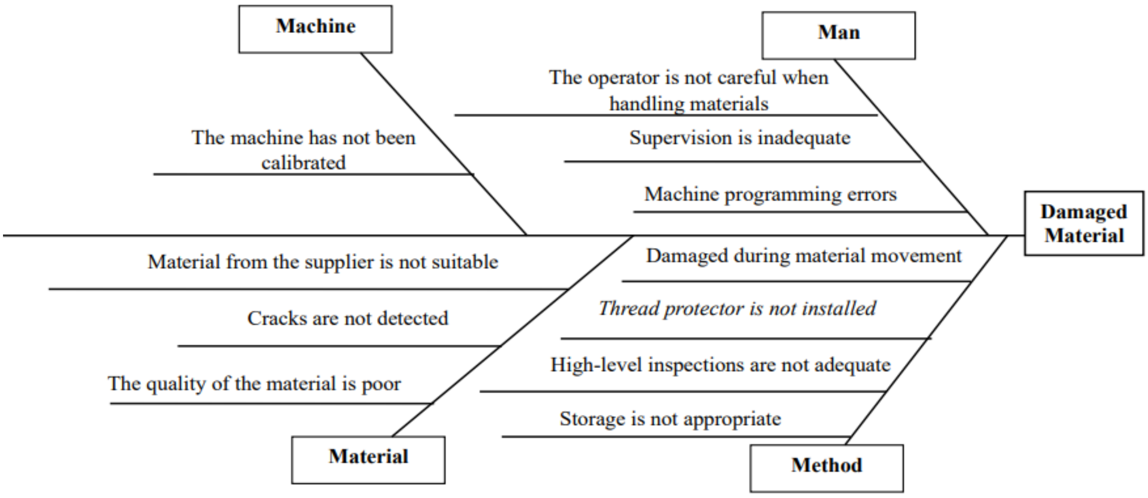

Figure 10. Fishbone diagram damaged material

4.4 Improve Stage

The proposed improvements are aimed at minimizing defects or discrepancies that occur to achieve product quality that meets standards. The proposed improvements are formulated using the Kaizen 5W1H method, which serves as a management tool encompassing who, what, where, when, why, and how. The analysis of the proposed improvements using Kaizen 5W1H is as follows (Table 3).

Table 3. Kaizen 5W1H for non-conforming cement test results

NO	Defect Occurred (What)	Time of Occurrence (When)	Location of Defect (Where)	Cause (Why)		Responsible Party (Who)	Improvement (How)
				Contributing Factors	Cause		
1	Non-Conforming Cement Test Results	Compresive Test	Dept. Quality Control	Man	Operators are not implementing actions according to work instructions	Production Operator (Cementing)	Provide reminders and ensure operators follow the production process according to existing work instructions.
				Material	Aggregate contains impurities and slurry	Production Operator (Cementing)	Wash aggregates before use.

				Quality of the water used is inadequate	Production Operator (Cementing)	Use water with a pH of no less than 6.
				The shape of the aggregate is not suitable	Production Operator (Cementing)	Use cone-shaped aggregates.
			Machine	Concrete mixer is not working properly	Production Operator (Cementing)	Regularly check, calibrate, and maintain the machines.
				Tools and machines have not been calibrated	Production Operator (Cementing)	
			Method	Materials are mixed improperly	Production Operator (Cementing)	Screen and separate materials according to their storage locations.
				Cement storage is not appropriate	Production Operator (Cementing)	Store cement in a suitable, dry, closed place, not in direct contact with the floor, and at a stable temperature.

Table 4. Kaizen 5W1H for unmatched components

NO	Defect Occurred (What)	Time of Occurrence (When)	Location of Defect (Where)	Cause (Why)		Responsible Party (Who)	Improvement (How)
				Contributing Factors	Cause		
2	Unmatched Components	Assembly Process	Dept. Assembly	Man	Human error	Production Operator	Conduct regular evaluations to identify the root causes of human errors that occur
					Operators are not meticulous and still make mistakes reading manufacturing drawings	Production Operator	Operators should carry out each stage of production carefully and without haste, and perform more thorough supervision
					Operators lack training in machine operation	Production Operator	Provide training to operators regularly and conduct routine evaluations
					Machine programming errors	Production Operator and Programmer	Recheck the machine program before the machining process and evaluate the program when errors are found
				Machine	The machine has not been calibrated	Production Operator	Perform regular calibration of the machines
				Method	Insufficient inspection at every stage of the production process	Production Operator	Conduct the production process carefully and without haste while following the established SOP and work instructions
					There are errors in determining sizes in the design drawings	Production Operator and R&D	Evaluate the manufacturing drawings, review them, and make updates to the manufacturing drawings

Table 5. Kaizen 5W1H for damaged material

NO	Defect Occurred (What)	Time of Occurrence (When)	Location of Defect (Where)	Cause (Why)		Responsible Party (Who)	Improvement (How)
				Contributing Factors	Cause		
3	Damaged Material	Machining Process	Dept. CNC	Man	Operators are not careful during material handling and there is a lack of supervision	Production Operator	Operators should carry out each stage of production carefully and without haste while performing more thorough supervision
					Machine programming errors	Production Operator	Recheck the machine program before the machining process
				Material	Material from the supplier is not suitable	QC Inspector	Seek alternative suppliers
					Cracks are undetectable	QC Inspector	
				Machine	The machine has not been calibrated	Production Operator	Perform regular calibration of the machines
				Method	Thread protector is not installed, leading to damage during material handling	Production Operator	Ensure thread protectors are installed and handle materials carefully during movement
					Storage is not appropriate	Production Operator	Store materials in a dry place protected from water, with good air circulation, stable temperature, and a flat surface

Overall, there are proposed improvements that can be made, which involve categorizing the types of defects and their causes, followed by the creation of a root cause analysis (RCA) for each error or discrepancy that occurs in order to understand the source of the problem. In the case study examined, the Six Sigma method was implemented by setting quality control objectives through historical data analysis and statistical analysis to reveal defects based on existing data. Based on the production process, it is possible to analyze the causal factors and actions that need to be taken. To implement it in the field, it is essential to involve all relevant and responsible parties and take direct actions, such as collecting actual defect data and applying corrective hypotheses directly to the root causes, as outlined in the improvement proposal. This allows for corrective actions to be taken and serves as a basis for continuous improvement. In theoretical implementation, the company can attempt to apply the Six Sigma method using recorded data to analyze and estimate the defect rate of the investigated product. Once identified, this can be implemented in practice by conducting experiments and making direct improvements to the root causes that have been analyzed, focusing on factors such as man, machine, method, material, and environment, as outlined in the improvement proposal section. This involves utilizing existing improvement methods to achieve tangible solutions and results.

5. CONCLUSION

Based on the stages of the Six Sigma method conducted in this study, a total production of 923 units of floating equipment was achieved, with 90 units found to be defective or nonconforming. There are five types of nonconformities: test results for cement not meeting specifications, unmatched components, damaged materials, incorrect dimensions, and incorrect thread profiles. In the calculation stage, a DPMO value of 19,501.62 was obtained, and a sigma quality level (SQL) of 3.5462 was determined, indicating that the production of floating equipment is at a 3-sigma level. The analysis stage was conducted using a cause and effect diagram to identify the factors causing the problems, which include man, machine, material, and method. Proposed improvements during the improvement stage utilized the Kaizen 5W1H method for each type of defect, allowing for the identification of the root causes of defects, the location of occurrences, and the parties responsible for implementing improvements. To facilitate ongoing improvements, it is hoped that the company will maintain comprehensive records of the types of defects, responsibilities, and conduct detailed root cause analyses for each error so that corrective actions can be taken and become part of continuous improvement. The proposed improvements emphasize training for production operators and addressing human errors, as well as maintaining and inspecting machines and other tooling, enhancing inspections and oversight, and paying attention to the storage and handling of materials used.

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