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ANALYSIS OF PRODUCT QUALITY BOGIE SET S2HD9C USING SIX SIGMA AND FMEA METHOD AT PT. BARATA INDONESIA (PERSERO)

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ABSTRACT

Product quality is critical for businesses to survive and thrive in the marketplace. Likewise with PT. Barata Indonesia (Persero), which always wants to provide good product quality for customer satisfaction, PT. Barata Indonesia (Persero) is a State-Owned Enterprise (BUMN) in the manufacturing sector, which has a business line in the foundry or foundry sector, one of which is the production of train components. The company's difficulty is that there are still problems in producing the S2HDC bogie set, such as break mold, porosity, slag, and crack. This study aimed to analyze the quality of the Bogie Set S2HD9C product using the six sigma method and propose improvements using Failure Mode and Effect Analysis (FMEA). The research results found that the percentage of defects that occurred during August 2022 - January 2023 was porosity of 40.38%, break mold of 30.77%, crack of 17.31%, and slag of 11.54%. To obtain an average DPMO of 14191 with a sigma value of 3.69. The causes of these defects are caused by human, material, machine, method, and environmental factors. From the FMEA analysis, the defect's cause is the highest RPN value of 392, with the proposed improvement to closely monitor the cleaning process and recheck the core box in every process that will use the mold.

Keywords: DMAIC, DPMO, Quality Control, Six Sigma.

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1. INTRODUCTION

1.1. Background

In the era of technological development like today, industrial business and manufacturing processes are critical in developing countries, both domestically and internationally. Every firm faces rapid and aggressive changes in the business environment; organizations compete in both local and global marketplaces; and product quality is vital for businesses to survive and prosper in the marketplace. (Novan & Suhartini, 2021). Usually, consumers will use products that provide satisfaction according to their needs. So maintaining consumer loyalty must be maintained if they want their products to continue to exist in the market. If a company wants their products to sell well in the market, they must maintain their quality (Basith, et al., 2020). Quality is a characteristic and overall character of a product that affects the product's ability to satisfy certain needs. Product quality is assessed based on the physical appearance, characteristics, and benefits of the product (Riandari, et al., 2022).

Quality is considered very important for organizations because it can improve a company's reputation, reduce costs, increase market share, increase product accountability, have an international impact, improve the appearance of products or services, and realize perceived quality (Faturochman, et al., 2020). Implementing a proper quality control system, having defined targets and phases, and providing innovation in preventing and fixing problems are all factors in generating product quality that meets requirements. Quality control actions can assist businesses in maintaining and improving the quality of their products by reducing product damage to a zero defect rate.(Nugroho & Kusumah, 2021).

PT Barata Indonesia (Persero) is a manufacturing company with business lines in a foundry or foundry manufacturing and manufacturing-based Engineering Procurement and Construction (EPC). PT Barata Indonesia (Persero) can produce Material Handling Equipment and Components for Railways, components, and machinery in the oil and gas or petrochemical sector, fertilizer, cement, and other industries, as well as steel construction. In the production process PT. Barata Indonesia (Persero) always wants to provide good product quality for customer satisfaction under increasing market needs.

A bogie is a construction consisting of two or more sets of wheels connected by a frame and equipped with a spring system, braking, with or without propulsion, and anti-skid equipment. The whole thing functions as a support for the base frame of the train body. A bogie is a set of wheels and a steel frame connected by a suspension system that functions to support and direct the movement of the train. (Monalisa, et al., 2022).

At the Foundry Factory (Foundry), producing several bogie set products from August 2022 – January 2023, one of the products with the largest production or demand is the S2HD9C Bogie Set product in its production. Several product defects still occur, namely with the types of Break Mould, Porosity, Slag, and Crack defects. The average disability that has happened is 5.7%. The defect exceeds the standard of companies that have zero defect targets.

So please note that market demand and competition are increasing, demanding that companies must have a competitive advantage because the products produced to supply the domestic market and provide added value through product export activities abroad, one of which is America. So PT. Barata Indonesia (Persero) plays an important role in producing train bogie components that must be able to compete at the international level. So with the problems that occur, this study aims to analyze product defects that occur in the S2HD9C Bogie Set and find out the sigma value, use the six sigma method, and provide improvement proposals with Failure Mode and Effect Analysis (FMEA) analysis to improve product quality at PT. Barata Indonesia (Persero).

This research can provide a very useful contribution for its application in the manufacturing sector, namely being able to find out how the quality of the Bogie Set S2HD9C product is at PT. Barata Indonesia (Persero) is able to provide suggestions for improvements to improve quality, as well as provide the author's knowledge, especially in the field of product quality control to be able to analyze defects. This research can show that the application of the Six Sigma method can reduce the value of DPMO (Defects per Million Opportunities) and increase the value of the Sigma level.

The six sigma method can help with business challenges by reducing the number of defects. The six sigma application focuses on faults and variations, beginning with identifying factors crucial to a process's quality and delivering suggestions for changes connected to errors that occur (Rahman & Perdana, 2021). According to (Pyzdek, 2003), Six Sigma is a quality concept that targets no more than 3.4 defects per one million products and is followed by increased customers. Implementing Six Sigma is hoped to satisfy customers, increase company profits or reduce production costs, and provide added value to companies in their business.

Quality control will be improved using the Six Sigma DMAIC concept and tools to eliminate product quality problems. DMAIC is a method for measuring sigma values that consist of define, measure, analyze, improve, and control (Ida, et al., 2021). The DMAIC methodology is the key to solving Six Sigma challenges and contains a series of incremental improvement phases, each of which is critical to reaching the desired results. (Ahmad, 2019). Companies must be able to apply the Failure Mode and Effect Analysis (FMEA) method to identify and evaluate the root cause of problems and discover solutions to improve the quality of the manufacturing process.

FMEA is a process, a set of guidelines, and a form for identifying and addressing potential issues. FMEA is used to discover failure methods, such as design flaws, conditions outside of specification limitations, or changes to goods that disturb their benefits (Primahesa & Ngatilah, 2022). FMEA is used to identify problems, collect data, analyze customer efforts and procedures, and implement six sigma initiatives. The first stage in FMEA preparation is calculating the value of the Risk Priority Number (RPN). (Pratiwi & Santosa, 2021).

2. METHODS

2.1 Data Collection

The research method is to collect data on field conditions, the number of products, problems that occur regarding quality control in the company, product defect data, and the percentage of defective products for the period August 2022–January 2023. The data source for this research begins by observing the processes that take place in production directly.

Researchers use the data collection method to obtain the required data. The data contained in this final project research are secondary data and primary data.

1. Secondary data in this last project research is the number of S2HD9C Bogie Sets produced each month, the number of product defects, and the type of product defects from the company.
2. Primary data is information gathered directly in the field. Interviews, observation, and documentation were used in this case.

2.2 Data Analysis and Processing

The data analysis method in this study uses Six Sigma and Failure Mode and Effect Analysis (FMEA). From interviews and observations obtained data information that product defects occurred in 104 units from August 2022 - January 2023 with the types of defect are break mold, porosity, slag, and crack.. According to (Gaspersz, 2005). The steps to execute Six Sigma quality improvement consist of five steps: DMAIC (Define, Measure, Analyze, Improve, and Control). The data processing methods employed in this investigation are as follows:

1. Define

Is one of the initial processes of the Six Sigma method to be able to find out the list rather than the number of defects (Wijaya, et al., 2021). In this stage, targeting and identification of Coal Crushers are carried out based on production data or is a phase of determining problems in the form of customer complaints or errors during production (Suryapradana & Halim, 2021). This phase describes the distribution of a data set, usually in the form of quality characteristics (Irwanto, et al., 2020).

2. Measure

The measurement is the second operational phase in the Six Sigma quality improvement methodology. Several major tasks must be completed, including (Bachtiar, et al., 2020) :

a. Choose or define critical quality characteristics (CTQ) that are closely related to the needs of the client.
b. It knows the degree of the defect using a Pareto chart.
c. It knows the degree of defects using a P-Chart.
   The control map has an upper line for the Upper Control Line and a lower line for the Central Line for the Average. the use of this p-control map is due to the quality control carried out is attributed. The steps in making a control map p are as follows:
   - Calculate the percentage of damage
     $p = \frac{\mathrm{np}}{\mathrm{n}}$……………………………(1)
     Information:
     p : Percentage of damage
     np : Number of failures in subgroups
     n : Checked number in subgroups
   - Calculate the center line (CL)
     $CL = \bar{P} = \frac{\sum np}{\sum n}$……………………(2)
     Information:
     $\bar{P}$: Average product damage
     CL : Control Limit
   - Calculate the Upper Control Limit (UCL).
     $UCL = \bar{P} + 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$……………(3)
     Information:
     $\bar{P}$: Average product damage
     n : Production amount
     UCL : Upper Control Limit
   - Calculate the Lower Control Limit (LCL).
     $LCL = \bar{P} - 3\sqrt{\frac{\bar{P}(1-\bar{P})}{n}}$……………(4)
     Information:
     $\bar{P}$: Average product damage
     n : Production amount
     LCL : Lower Control Limit
     (Abdurrahman & Al-Faritsy, 2021).
d. Determine DPMO value and Sigma Level.
   In this phase, control charts are used to measure process stability, identify parameters outside the specification, calculate DPMO values for variable data, calculate sigma values obtained from the DPMO value conversion table into sigma levels, and measure process capability.

   DPO= $\frac{number\ of\ defective\ products}{total\ amount\ of\ production\ CTQ}$ ...(5)

   DPMO = DPO x 1.000.000……….......(6)
   (Tukan & Pattiasina, 2019).

3. Analyze

At this stage of the analysis, an analysis of the data that has been obtained will be carried out using a cause-and-effect diagram.(Pahmi & Pahmi, 2020). This stage involves assessing, searching for, and determining the source of an issue. It can use the Six Big Losses analysis to show causal factors and quality characteristics. In this cycle, the root cause of potential problems from key CTQ will be determined with the help of fishbone (Novan & Suhartini, 2021). The cause and effect diagram is a diagram that shows the relationship between cause and effect in a problem that shows the causal factors and root cause characteristics of the issue found, including Man (labor), Machines (machines), Methods (work methods), Materials (raw materials and auxiliary materials), and Money (finance). One of the benefits of a fishbone diagram is that it can reduce and eliminate conditions that cause product or service disagreements and customer complaints.

4. Improve

The Improve step is to determine the priority causal factor for the highest value of disability by calculating the value of the Risk Priority Number (RPN) in the Failure Mode Effect Analysis (FMEA) method and giving recommendations for improvement on the causal factor of the disability with the highest RPN value. (Purnomo, et al., 2022)In this stage, Failure Mode and Effect

Analysis (FMEA) is used. FMEA's primary goal is to identify potential failure modes within system units, evaluate their subsequent effects on system performance, and then recommend strategies to eliminate or reduce the likelihood of occurrence or severity, as well as improve the detection of specific failure modes. (Lo & Liou, 2018). After analysis of the factors causing failure, the failure mode is prioritized based on the Risk Priority Number RPN from the highest to the lowest with the following formula:

$RPN = S \times O \times D$ ………………………….(6)

Information:

S : Severity

O : Occurrence

D : Detection

5. Control

Control is carried out by designing quality improvement results and integrating Six Sigma results concerning company standards (Usman & , 2021). The outcomes of quality improvement are documented and communicated at this level. Successful process improvement best practices are standardized and exhibited as standard guidelines and ownership or responsibility is transferred from the team to the process owner or person in charge. (Sutiyarno & , 2019)

3. FINDINGS AND DISCUSSION

3.1. Findings

Data collection taken from research in the company is in the form of production quantity data and product defect data produced during the production process. This study used Bogie Set S2HD9C product data at PT. Barata Indonesia (Persero). Based on the observations, several types of defects in Bogie Set S2HD9C products were obtained: Break Mould, Porosity, Slag, and Crack. Data on the number of S2HD9C Bogie Set production used from August 2022 to January 2023 can be shown in the data below:

Table 3. Data on the Production of S2HD9C Bogie Set for August 2022 – January 2023

Month	Production Quantity (Unit)	Number of Production Defects (Unit)
August 2022	248	14
September 2022	195	10
October 2022	348	16
November 2022	222	13
December 2022	495	33
January 2023	292	18
Total	**1800**	**104**

Source: PT. Barata Indonesia (Persero)

Based on Table 4.1, it can be seen that the total production of S2HD9C Bogie Set for August 2022 – January 2023 is 1800 units, and the highest production amount occurred in December 2022 at 495 units, while the lowest production amount occurred in September 2022 at 195 units.

The defect data of the S2HD9C Bogie Set product used is from August 2022 to January 2023, which can be shown in the following data:

Table 4. S2HD9C Bogie Set Product Defect Data for August 2022 – January 2023

Month	***Types of Defects* (Unit)**				Defect Products
	Break Mould	**Porosity**	**Slag**	**Crack**	
August 2022	2	2	2	8	14
September 2022	2	5	2	1	10
October 2022	10	3	2	1	16
November 2022	2	6	1	4	13
December 2022	3	24	4	2	33
January 2023	13	2	1	2	18
Total	**32**	**42**	**12**	**18**	**104**

Based on Table 4. above, it can be seen that the total defects of S2HD9C Bogie Set products for August 2022 – January 2023 are 104 units. The largest total defect occurred in December 2022 at 33 units, and the smallest total defect occurred in September 2022 at 10 units.

3.2. Discussion

Data processing steps from product quality problems are DMAIC (define, measure, analyze, improve, control).

1. Define

The Define stage is the first phase in the six sigma technique, where the object to be researched must be identified. Problems that PT often faces. Barata Indonesia (Persero) has many defects in the production process of S2HD9C bogie sets. Then a histogram chart can be made for August 2022 – January 2023 to determine the number of defects that occur.

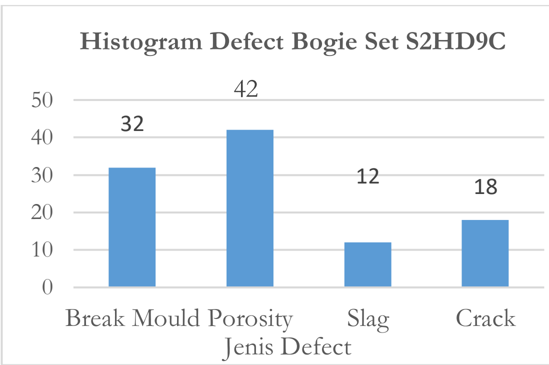

Figure 1. S2HD9C Bogie Set Defect Type Histogram Chart for August 2022 - January 2023

2. Measure

a. Identifying Critical To Quality (CTQ).
   The first step in the measuring stage is determining the quality characteristics or Critical To Quality (CTQ) on the S2HD9C bogie set product. CTQ on the product consists of 4 CTQs, namely:
   - Break Mold
     It is a defect in the form of a shape that does not match the mold, which results in an untidy shape in the casting bogie.
   - Porosity
     Defects of porosity products are defects in the form of small holes in the casting bogie.
   - Slag
     It is a defect in the form of slag or waste, in the form of lumps of metal that are difficult to separate, which results in very dirty bogie casting.
   - Crack
     It is a product defect in the form of cracks in the casting bogie.

b. It knows the degree of the defect using a Pareto diagram.
   The data is processed into a bar graph divided by type of damage, from the highest data on the left to the smallest on the right (Kuswardani, et al., 2020). The calculation of the percentage of defects in August 2022 – January 2023 obtained a Pareto diagram as follows:

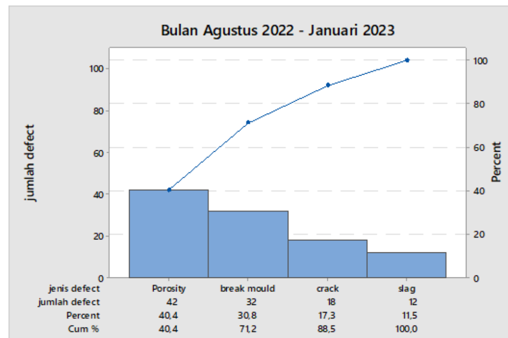

Figure 2. Pareto Defect Diagram for August 2022 – January 2023

   From Figure 2. Above, it is known that the highest to lowest defect percentage in August 2022 – January 2023 is defect porosity of 40.38%, followed by defect break mold of 30.77%. The defect crack is 17.31%, and the lowest is slag at 11.54%.

c. It knows the degree of defects using a P-Chart.
   Making a control map aims to determine whether a production process is running well and whether the number of product defects is still within or outside the control limit. If the value of the proportion of defects of a subgroup is above UCL or below LCL, it will be counted as data that is out of control.
   - Defect Break Mould
     The calculations show that the defect break mold in August 2022 – January 2023 has a center line value of 0.018. So that the defect break mold control map is as follows:

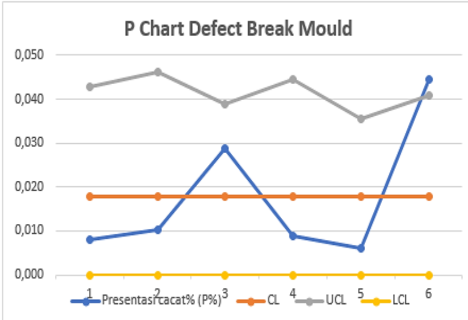

Figure 3. Control Map P on Defect Break Mold

From Figure 3. Above, it can be seen that the data for January 2023 is out of control, so improvements still need to be made to achieve zero defects.

- Defect Porosity

  Defect porosity in August 2022 – January 2023 has a Center line value of 0.023. So that the defect porosity control map is as follows:

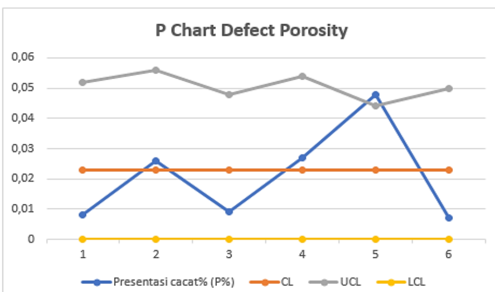

Figure 4. Control Map P on Defect Porosity

From Figure 4. Above, it can be seen that the December 2023 data is out of control, so improvements still need to be made to achieve zero defects.

- Defect Slag

  Defect slag in August 2022 – January 2023 has a Center line value of 0.007. So that the defect slag control map is as follows:

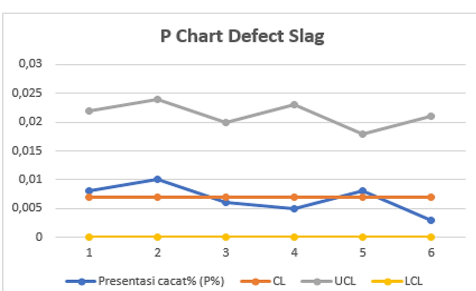

Figure 5. Peta Kontrol P pada Defect Slag

From Figure 5. Above it, the defect slag data is not out of control.

- Defect Crack

  The defect crack in August 2022 – January 2023 has a Center line value of 0.010. So that the defect crack control map is as follows:

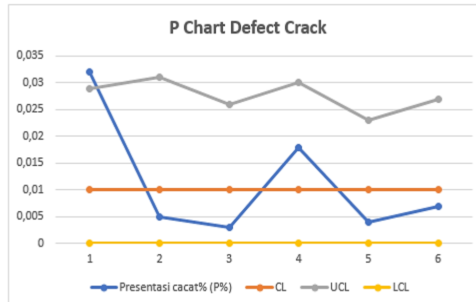

Figure 6. Control Map P on Defect Crack

Figure 6. Above, it can be seen that the December 2023 data is out of control, so improvements still need to be made to achieve zero defects.

d. We are determining DPMO value and Sigma Level.

   Based on the DPMO and six sigma calculations, the following recapitulation of the DPMO calculation and sigma level on the S2HD9C Bogie Set product from August 2022 to January 2023 may be made:

Table 5. DPMO Calculation Results and Sigma Level of S2HD9C Bogie set products from August 2022 – January 2023

Bulan	**DPO**	**DPMO**	***Level Sigma***
Agustus 2022	0,0141	14113	3,694
September 2022	0,0128	12821	3,732
Oktober 2022	0,0114	11494	3,774
November 2022	0,0146	14640	3,680
December 2022	0,0166	16667	3,628
January 2023	0,0154	15411	3,659
TOTAL	**0,085**	**85144**	**22,166**
Average	**0,01419**	**14191**	**3.69**

Based on Table 5. above, shows that according to the Six Sigma conversion table, PT Barata Indonesia (Persero) is at the level of 3.69 or can be said to be at the level of 3σ with an average DPMO value of 14,191 per 1,000,000 productions carried out by PT Barata Indonesia (Persero). So it can be said that the company still has not met the target towards a world-class or 6σ level corporate standard. Therefore, it is necessary to make improvements by analyzing the factors that cause defects so that the company's sigma value can approach the matter of 6σ.

3. Analyze

Determination of the root cause of CTQ using a fishbone diagram.

a. Fishbone Diagram for Break Mold Defect

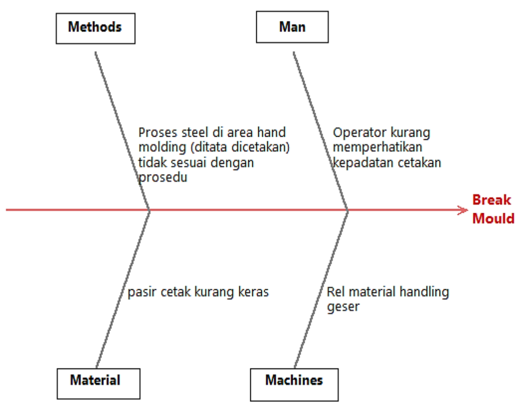

Figure 7. Fishbone of Break Mold Defects

In Figure 7. Above, it can be seen that a defect break mold has four factors that cause failure: method, human, material, and machine.

b. Fishbone Diagram for Porosity Defect

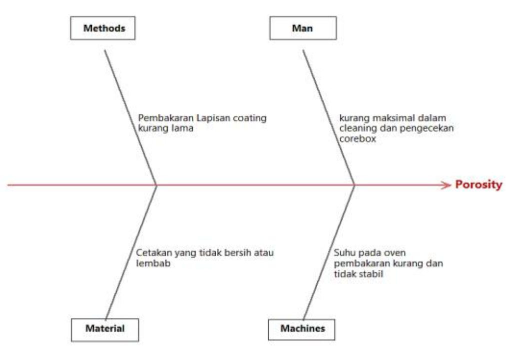

Figure 8. Fishbone of Porosity Defects

In Figure 8. Above, it can be known that defect porosity has four factors that cause failure: method, human, material, and machine.

c. Fishbone Diagram for Slag Defect

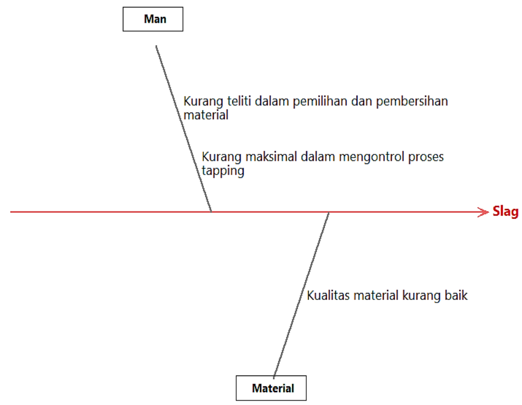

Figure 9. Fishbone of Slag Defects

In Figure 8. Above, it can be seen that defect slag has two factors that cause failure: human and material.

d. Fishbone Diagram for Crack Defect

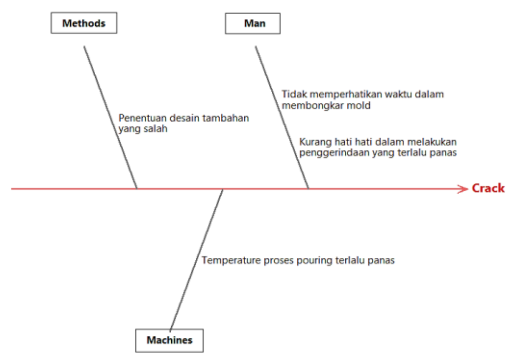

Figure 10. Fishbone of Crack Defects

In Figure 10. Above, it can be known that defect slag has three factors that cause failure, namely method, human, and machine factors.

4. Improve

This improvement plan is the result of discussions with the company where the proposed improvements made can provide input so that the number of defects can be reduced; improvements are carried out using the Failure Mode and Effect Analysis (FMEA) method.

An analysis of the factors causing the failure was carried out of the four defects that occurred, and recommendations for improvement were made to reduce the defects that occurred.

a. FMEA of Break Mold Defect

Table 6. FMEA analysis of break mold defects

Priority Number	Cause of Failure	RPN	Recommendation
1	Operators pay less attention to mold density	210	Check and fine-tune the density of the mold again before the mold is heated.
2	Sliding material handling rails	196	Set a definite maintenance schedule to add rail material handling maintenance.
3	The steel process in the hand molding area (when laid out is molded) is not following the procedure	112	Rechecking is carried out by the tapping section operator carefully when the mold will be used in the next process.
4	Frog sand is less hard	84	Consider more about using used sand by the proper composition and can replace silica sand that is already fine with silica sand that is still hard.

Based on Table 6. above is sorted by priority number from the largest to smallest RPN value, operator conditions that do not pay attention to the density of the mold get the largest RPN value of 210 with the recommendation to check and perfect the molding density again before the mold is heated. Up to the smallest RPN value of 84 with improvement, recommendations Consider more about using used sand by the proper composition and can replace silica sand that is already fine with silica sand that is still hard.

b. FMEA of Porosity Defect

Table 7. Analysis of FMEA defect porosity

Priority Number	Cause Of Failure	RPN	Recommendation
1	Less optimal in cleaning and checking the core box	392	Closely monitor the cleaning process and recheck the core box in every process using molds.
2	Burning Coating Coating Less Long	245	Always ensure the engine settings follow the provisions and that the operator on duty has been trained to know the standards that have been determined.
3	The temperature in the combustion oven is less unstable	168	Scheduling maintenance for engine maintenance so that the combustion temperature becomes stable and controlling the temperature during the combustion process
4	Immature or damp mold	105	Selecting materials starting from suppliers to return scrabs contaminated with oil or oil.

Based on table 7. above is sorted by priority number from the largest to smallest RPN value for less than optimal conditions in cleaning and checking core boxes get an RPN value of 392 with recommendations for improvement, closely monitoring the cleaning process and rechecking the core box in every process that will use molds. Up to the smallest RPN value of 105 with recommendations for repair, selecting materials from suppliers to return scrabs contaminated with oil or oil.

c. FMEA of Slag Defect

Table 8. Analisis FMEA defect slag

Priority Number	Cause of Failure	RPN	Recommendation
1	Lack of meticulousness in material selection and cleaning	150	Giving direction to workers in selecting good materials and conducting training to be more skilled in cleaning materials
2	Poor material quality	125	Be more selective when checking materials coming from suppliers. If the material obtained from many suppliers is not good, they can switch to other suppliers who are more guaranteed quality.
3	Less optimal in controlling the tapping process	60	Provides a dirty material detection indicator so that inappropriate material is not poured into the mold

Based on table 8. above is sorted by priority number from the largest to smallest RPN value for conditions Less careful in material selection and cleaning gets an RPN value of 150 with recommendations for improving giving directions to workers in selecting good materials and conducting training to be more skilled in cleaning materials. Up to the smallest RPN value of 60 with repair recommendations provides indicators to detect dirty material so that inappropriate material is not poured into the mold.

d. FMEA of Crack Defect

Table 9. FMEA analysis of crack defect

Priority Number	Cause of Failure	RPN	Recommendation
1	Lack of caution in carrying out ground that is too hot	144	Provide time for pauses so there is no overheating in grinding, and training can be done for operators to maintain their skills.
2	The temperature of the pouring process is too hot	120	Adjust the temperature and add bracket shapes to resist cracking to neutralize heat during pouring.
3	Not paying attention to the standard time in disassembling the mold	96	Set the normal limit of mold disassembly time correctly
4	Incorrect determination of additional designs	72	Providing training to workers to be more skilled in carrying out additional designs following material conditions that must be repaired

Based on Table 9. The above is sorted by priority number from the largest to the smallest RPN value, for the condition of the operator being less careful in carrying out overheating grinding gets an RPN value of 144 with improvement recommendations to provide time for pauses so as not to overheat in grinding, and training can be done for operators so that their skills remain consistent. Up to the smallest RPN value of 72 with recommendations for improving the provision of training to workers to be more skilled in carrying out additional designs following the material conditions that must be repaired.

5. Control

The final stage of Six Sigma quality analysis is the control stage. At this stage, the results of quality improvement are documented, good practices are formed and used as standard work rules, and accountability is handed to the process's owner or person in control. Provide proposals for actions to improve product quality in the hope of achieving better goals, in this case, companies that supervise product quality.

4. CONCLUSION AND SUGGESTION

4.1 Conclusion

Based on research that has been conducted at PT. Barata Indonesia (Persero) then can be concluded as follows:

1. Based on the results of data processing using the six sigma method in August 2022 – January 2023, it can be known that the DPMO value of product quality is 14,113 with a Sigma value of 3.69, which means that it still does not meet the target of world-class or 6σ company standards desired by PT. Barata Indonesia (Persero). This research makes a very useful contribution to the field of manufacturing by providing the results of a sigma value to a company for evaluation to compete with other companies. The application of the Six Sigma method can increase the sigma value that occurs at PT. Barata Indonesia (Persero).
2. The improvement proposal with the FMEA method obtained the highest RPN value ranking of 392, which can be given improvement proposals, closely monitoring the cleaning process and rechecking the core box in each process that will use molds, then the RPN value of 245 can be given repair proposals always ensure the engine settings are following the provisions and ensure that the operator on duty has been trained to know the predetermined standards.

4.2 Suggestion

Based on these conclusions, suggestions for companies and further researchers include::

1. With this research, companies should be able to review the factors that cause product defects that occur as an evaluation for the future.
2. The company must maintain and improve the quality and performance ability of employees on duty as the operator and quality control.
3. Companies can consider the outcomes of proposed improvements to be adopted and companies to minimize the occurrence of product defects by using the Six Sigma approach and failure mechanism and effect analysis (FMEA)..

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