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QUALITY IMPROVEMENT IN CYLINDER BLOCK PRODUCTION: A SIX SIGMA APPROACH AT PT. XYZ

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Abstract

The implementation of Six Sigma methodology has demonstrated significant effectiveness in enhancing quality and reducing defects in manufacturing processes. This study examines the application of Six Sigma principles to minimize defects in automotive cylinder block production. Employing the Define, Measure, Analyze, Improve, and Control (DMAIC) framework, the research identifies critical factors contributing to defects and implements strategic improvements to address quality issues. The Define phase established key elements related to quality products, including processes, suppliers, customers, and their requirements, utilizing SIPOC diagrams and Critical to Quality (CTQ) factors. In the Measure phase, data collection focused on determining process baselines and root causes, employing Defects Per Million Opportunities (DPMO) and Control Charts. Analysis revealed a DPMO value of 4,987 with a sigma level of 4.077σ. The Analyze phase identified causes of production process failures, with "Sunakui" (sand hole) emerging as the predominant defect type in cylinder block production. The study concluded that unsuitable sand composition was the root cause leading to defects. To address this issue, the research recommends implementing a Poka-Yoke system with an integrated alarm to monitor and ensure appropriate sand composition, thereby enhancing overall product quality.

Keywords: *Six Sigma; defect; sand molding; cylinder block; automotive*

1. Introduction

Every manufacturer strives to deliver high-quality products meeting customer expectations. Understanding quality criteria aligned with customer needs is crucial. Consistently providing superior products enhances satisfaction. Effective quality control is key to preventing defects and ensuring only quality products reach consumers. This approach minimizes dissatisfaction and maintains the company's reputation for excellence.

The automotive industry, characterized by its rigorous quality standards and competitive nature, continuously seeks methods to enhance production efficiency and product quality. A critical component in automotive manufacturing is the cylinder block, a central part of an engine's structure (Filho, 2013). The production of cylinder blocks involves complex casting processes, where defects can significantly impact the overall quality and performance of the final product. To address these challenges, many manufacturers aimed at reducing variability and defects in production processes.

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This study focuses on PT. XYZ, a prominent automotive component manufacturer located in West Java, Indonesia. Specializing in diesel automotive components, PT. XYZ produces 162 different types of parts, categorized into engine parts, transmission and axle parts, and wheel and brake parts. The company's primary product is the cylinder block, manufactured using the Kanban system, a pull-based production method. The finished components are then sold to customers for engine and unit assembly. While the company has successfully expanded its market reach both domestically and internationally, with Thailand as its primary export destination, it faces significant challenges in its production processes.

PT XYZ itself already has various kinds of certifications, such as ISO-9001:2000, ISO-14001:2015, and IATF 16949:2016 (Quality Management System). However, PT. XYZ is facing a high occurrence of defects in its manufacturing operations, particularly in the production of cylinder blocks. These defects result in products that fail to meet established quality standards, necessitating their remelting through the melting process. This not only increases production costs but also reduces the efficiency of finished product supply. Furthermore, when defective products are identified, the quality control department must conduct extensive checks on entire production lots, potentially leading to product recalls from customers. Addressing these challenges is vital for maintaining competitive advantage and ensuring product quality.

The Six Sigma methodology has gained prominence as an effective approach for improving manufacturing quality and efficiency. Six Sigma, developed by Motorola in 1987, is a data-driven quality control and improvement method that focuses on minimizing variability in manufacturing and business processes (Gaspersz, 2002). The Six Sigma method is a technique used to achieve an operational performance of 3.4 defects per million opportunities or activities. Six Sigma's uniqueness lies in its emphasis on a thorough understanding of facts, data, and statistical analysis, along with careful business management, repair, and reinvestment. The utilization of Six Sigma can result in cost savings, productivity improvements, market share expansion, defect reduction, and the enhancement of manufacturing or service quality (Pande, Neuman, & Cavanagh, 2000).

Several studies have demonstrated the effectiveness of Six Sigma in the automotive industry. Priya. et al. (Priya, Jayakumar, & Kumar, 2020) reported a significant reduction in defect ratio by 37.2% in an automotive assembly line. Similarly, Guleria et. al (Guleria, Pathania, Sharma, & Carlos, 2022) achieved a substantial reduction in defect rates in an automobile axle manufacturing plant, lowering the defect rate from 10.4% to 3.2%. Furthermore, Jou et. al. (Jou, Silitonga, Lin, Sukwadi, & Rivaldo, 2022) improved the Six Sigma value of brushed and brushless DC motors from 5.11 to 5.44. These diverse examples across different automotive manufacturing processes—from assembly lines to specific component production—highlight the versatility and efficacy of Six Sigma in enhancing quality and reducing defects in the automotive sector.

With its robust framework for identifying and mitigating sources of defects, the Six Sigma methodology offers a promising approach for achieving quality improvement goals. By systematically analyzing and improving production processes, Six Sigma helps in reducing variability and enhancing product consistency. This research aims to investigate the root causes of defects in the cylinder block production in PT XYZ. By focusing on this specific case study, we aim to contribute to the broader understanding of Six Sigma applications in the automotive component manufacturing industry.

2. Research Methods

Since the launch of the initial six-step procedure by Motorola University's Design for Manufacturing training program in 1988 (Watson & Deyong, 2010), the Six Sigma approach has been a prominent method in the Quality Management field due to its benefits in quality improvement (Green, 2006). Adopting Six Sigma can provide numerous benefits. It can improve product development and reduce manufacturing cycle times, resulting in shorter product lead times. Six Sigma helps identify and eliminate fundamental causes of problems, decreasing process variability and preventing defects (Tjahjono et al., 2010).

Six Sigma is defined as a statistical methodology used in quality management to enhance processes (Goh & Xie, 2004; Mcadam & Evans, 2004). The goal is to improve Six Sigma performance indicators, namely Critical to Quality (CTQ), by analyzing data using technologies that represent customer expectations. Statistical techniques identify the major quality measure, Parts per Million (PPM), for nonconforming items (Mitra, 2004). Six Sigma requires a process with less than 3.4 defect parts per million (Coleman, 2008). It is accomplished by identifying and eliminating the source of defect and unpredictability in the production process.

The sigma scale of measure is associated with features such as defects-per-unit, parts-per-million defectives, and the chance of failure. Additionally, it symbolizes the fluctuation of the procedure. Six is the value of sigma in a process, when the level of variation around the objective is sufficient that only 3.4 outputs out of one million are considered as defects (Mitra, 2004). The phrase Six Sigma refers to a process that has a defect rate of fewer than 3.4 faults per million opportunities (DPMO). When a corporation achieves five-sigma performance levels, it indicates a 233 DPMO and so on (Goh & Xie, 2004). This approach allows firms to assess their current performance and use sigma level analysis to identify areas for improvement.

The Six Sigma methodology is applied to various processes, including the improvement of shoe sole quality (Wijaya, Trusaji, Akbar, Ma'ruf, & Irianto, 2018), automotive product manufacturing (Gupta, Jain, & Dangayach, 2018; Rinawati, Andini, & Sari, 2019; Venkatesh, Gowrishankar, & Sumangala, 2014) and garment industry (Nupur, Gandhi, Solanki, & Jha, 2018).

The DMAIC cycle—which stands for define, measure, analyze, improve, and control—is implemented by the Six Sigma technique and is frequently employed as a strategy for continuous improvement. (Montgomery, 2009):

1. Define is the step of identifying existing problems, defining the process that causes the problem, which will affect the product's quality, and determining the completion target.
2. Measurement is a step in an ongoing system process that involves establishing reliable and valid measurements that help monitor progress toward the targets set.
3. Analyze involves identifying causal links in the process and understanding the causes of variability. In other words, this stage seeks to identify the probable sources of defects, quality issues, customer difficulties, procedures, and output issues, as well as waste and inefficiencies that drive processes.
4. The improve step involves creative thinking to identify modifications that can be implemented in the process and explore various strategies to improve process performance.
5. Control is a step toward ensuring that changes are carried over all of processes. The process control

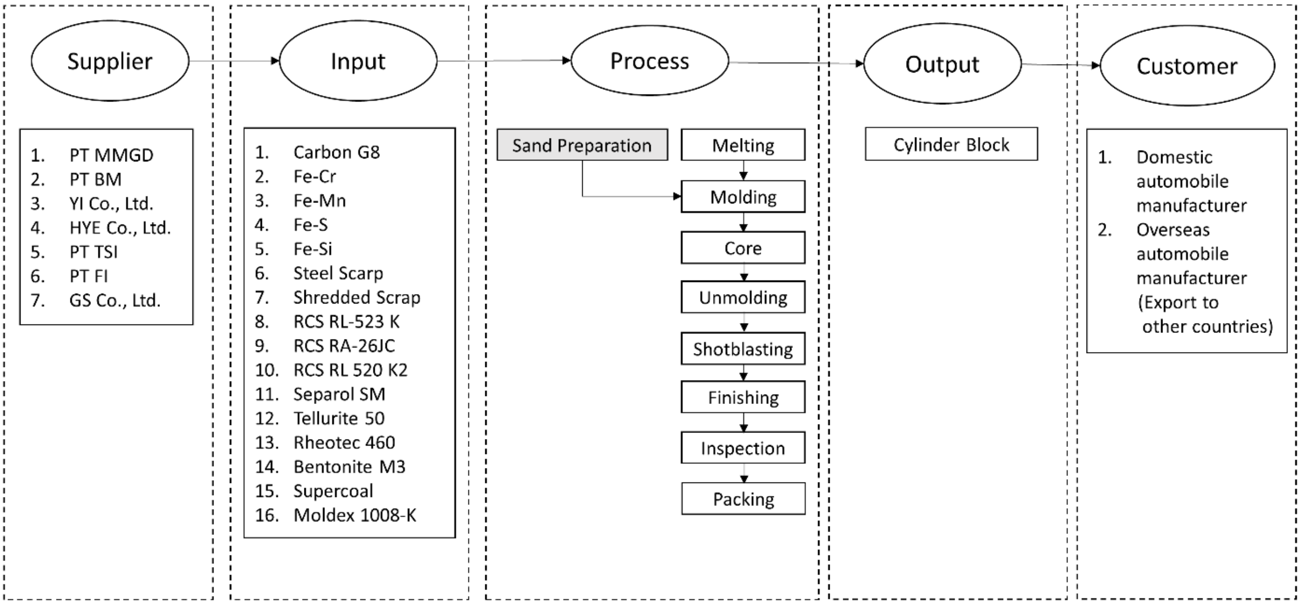

Figure 1. SIPOC Diagram

plan should be a mechanism for monitoring the implemented solutions, including methodologies and metrics for regular checks.

The collected data includes production, defects, and raw material data in December 2023.

In this study, the Six Sigma DMAIC methodology was utilized to improve the casting process for cylinder blocks. Each phase of the DMAIC process involved a combination of qualitative and quantitative techniques. The Define phase characterized the problem, identified stakeholders affected by nonconforming products, and analyzed the processes involved. Pareto and SIPOC (Supplier-Input-Process-Output-Customer) diagrams were utilized to gain a comprehensive understanding of the cylinder block production process. Critical-to-Quality (CTQ) characteristics were identified based on defect types. The Measure phase involved calculating DPMO (Defects Per Million Opportunities) and sigma values. The Analyze phase studied causal relationships to determine dominant factors requiring control, with root cause identification being critical. These factors were then analyzed using the Failure Mode and Effects Analysis (FMEA) technique. FMEA prioritizes issues for immediate resolution by calculating Risk Priority Numbers (RPNs) based on the product of Severity, Occurrence, and Detection ratings. This approach enables teams to focus their efforts on the most critical problems first, ensuring efficient use of resources in quality improvement initiatives.

The Improve phase identified primary sources of difficulty and made recommendations based on earlier analyses. Improvement ideas to eliminate defects in cylinder block manufacturing were developed using the risk control hierarchy. In this stage, the 5W+1H approach tools are employed. This approach involves systematically addressing six key questions: What occurred, who was involved, why it happened, when it took place, where it occurred, and how it came about.

In the Control phase, mechanisms were designed to ensure implementation activities followed the plan and solutions could be sustained. This systematic approach led to significant improvements in the cylinder block casting process, reducing defects, and enhancing overall quality.

3. Result & Discussions

To adopt Six Sigma method, various stages must first be established, including define, measure, analyze, identify, and control.

3.1. Define

The define stage is the first phase of DMAIC, identifying processes, goods, suppliers, consumers, and customer standards for high-quality products.

3.1.1 SIPOC Diagram

SIPOC is a tool that visualizes the flow of business operations from suppliers to customers, left to right. The SIPOC diagram in **Figure 1** illustrated the production flow including supplier, input (raw material), process production, output of the process, and the customer of the product output. The production process includes several stages: sand preparation, melting, molding, core, cooling, mold unloading, shot blasting, finishing, inspection, and packing, resulting in the output of cylinder blocks. These cylinder blocks are then marketed to both domestic and international customers.

3.1.2 Critical to Quality (CTQ)

The Cylinder Block product is a Crl2 type casting with a minimum tensile strength standard of 24 Kgf/mm2. This product uses FC 250 material with a hardness of 197 - 241 HB. The functions of this product are as follows:

1. Housing for cylinders where pistons move up and down to perform their work.
2. Serves as a mounting surface for the cylinder head.

Table 1. Defect Types of the Cylinder Block

Defect	Description
Blow hole/ Fukare	A cavity defect that can appear as pinholes or subsurface blowholes. These are rounded or oval cavities caused by gases trapped by solidifying metal on the casting surface
Sand hole/ Sunakui	A defect on the product surface with round shapes, dark inner surfaces, and sand particles appears
Hadaare	This defect characterized by many small holes on the casting surface
Sand burning or Yakitsuki	Also known as burn-on or metal penetration, this defect involves thin sand crusts firmly adhering to the casting surface
Cold lap or Yuzakai,	A defect characterized by the presence of a layer on the casting surface.
Nakago Hason	A defect caused by a damaged mold, resulting in an imperfect product.
Sand inclusion/ Norokui	Irregularly formed sand inclusions close to the casting surface, often combined with metallic protuberances at other points
Norikui	Defect caused by exogenous inclusions or trapped slag.
Mechanical Damage/ Dakon	Damage during machining or shipping processes.
Shrinkage Cavities/ Hike	Severe shrinkage defect characterized by an irregular shape and sharp inner surfaces
Sukuware	The defect characterized by casting flakes adhering to the product surface
Yoniku	A defect caused by a chipped or damaged mold, resulting in excess casting material during the pouring process.
Togatakui	A defect characterized by an irregular (non-round) shape with a smooth and dark inner surface.
Yumore	Incomplete casting defect
End Rear Crack	A defect that occurs due to impact or collision with other products on the end rear section

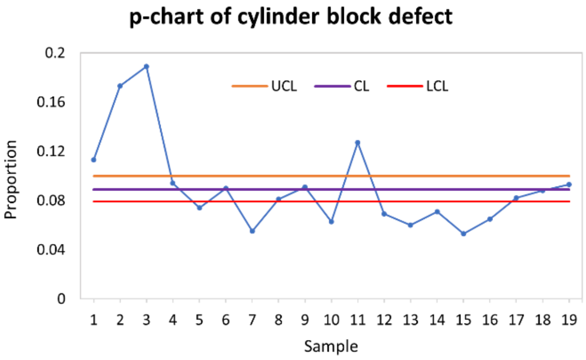

Figure 2. Control Chart

3. Acts as a support for the crankshaft or as a housing for the crank mechanism (crankshaft, connecting rod, piston, and other components).
4. Provides a mounting point for the flywheel.
5. Contains a water jacket that serves as a channel for water to cool engine components.
6. Serves as a mounting base for other components, such as the distributor, starter motor, alternator, and others.

With those various functions, the cylinder block was designed to meet these criteria:

1. Rigidity: The block must maintain its structural integrity under pressure loading, without experiencing elastic deformation that could alter its shape.
2. Strength: The manufactured product must be robust and durable.
3. Thermal management: The product's construction must allow for uniform cooling and possess excellent heat dissipation capabilities.
4. Thermal expansion compatibility: The block's thermal expansion characteristics must be compatible with the components mounted on it, such as the crankshaft.

The manufacturer classified various defects of the product as described in **Table 1**. Furthermore, the CTQ of this product is defined based on the type of its defect.

3.2 Measure

The Measure phase assesses the company's Quality Control using various tools.

3.2.1 Defect per Million Opportunities (DPMO)

The performance of cylinder block's casting process has been evaluated using defect fraction and DPMO to assess stability and process capability. According to calculations, the sigma rate for cylinder block production is 4.077, with a probability of 4,987 defects per million productions. According to the sigma value, the production process is fairly good. However, the production process's sigma value needs to be improved as it did not meet the sigma level of 4.5.

3.2.2 Control Chart

The Control Chart indicates whether the manufacturing process is within control limits on each day, as shown in **Figure 2**. **Figure 2** demonstrates that the production process is indeed not going well. The number of data points (representing days) that fall

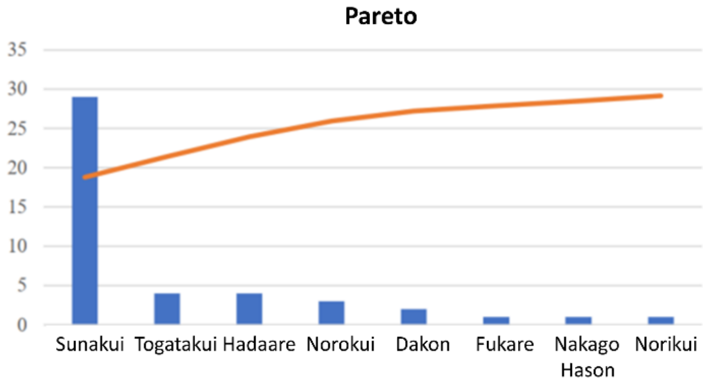

Figure 3. Pareto Diagram of Non-Conforming Cylinder Block

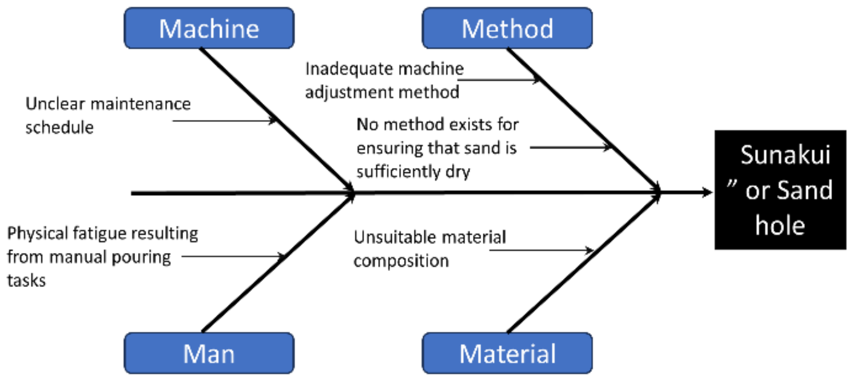

Figure 4. Fishbone Diagram of "Sunakui" Defect.

Table 2. FMEA of "Sunakui" Defect

Factor	Process	Cause	Effect	S	O	D	RPN
Material	Sand preparation	Unsuitable sand composition	Low permeability of the molding sand and excessive moisture content	7	6	8	336
Machine	Molding	Unclear maintenance schedule	The pouring cup and gating system are wet, lowering its permeability	6	5	6	180
Method	Molding	Inadequate machine adjustment method	Sand clumps in the Flask	7	3	3	63
Man	Molding	Slow pouring	Physical fatigue resulting from manual pouring task	6	3	5	90
Method	Unmolding	No method exists for ensuring that sand is sufficiently dry	The sand is insufficiently dry causing a high chance of small holes in the product	7	6	7	294

outside the control limits is a clear indication of process instability and the need for corrective action. This situation calls for a thorough investigation of the factors causing these out-of-control conditions, particularly on days 1, 2, 3, and 11, to improve the overall stability and reliability of the production process.

3.3 Analyze

3.3.1. Pareto Diagram

The Pareto diagram was employed to determine what problems occur most frequently. Eight defect types were most experienced in cylinder block products, as shown in **Figure 3**. This graph shows that "Sunakui" represented the most prevalent type of defect, constituting approximately 64% of the total defects observed. While Togatakui, Hadaare, Norokui, Dakon, Fukare, Nakago Hason, and Norikui all have a percentage of defective products. Furthermore, the cause of the "Sunakui" issue will be searched by using a Fishbone Diagram.

3.3.2. Fishbone Diagram

The Fishbone Diagram is a thorough method for determining the root cause from four criteria: man, method, machine, and material. **Figure 4** illustrates the fishbone diagrams for the "Sunakui" problem.

3.3.3 Failure Mode and Effect Analysis (FMEA)

FMEA is utilized to identify the primary causes of "*Sunakui*" defects, necessitating the formulation of improvement recommendations as shown in **Table 1**. Based on the FMEA calculations in **Table 2.**, the potential failure mode with the highest RPN value is incorrect or unsuitable sand composition, making this potential failure mode the top priority. The RPN value of 336 is obtained by multiplying the Severity (S),

Table 3. 5W+1H on “Sunakui” Defect

No	5W + 1H	Answer
1	What?	Low permeability of the molding sand and excessive moisture content
2	Why?	No
3	When?	At sand preparation process
4	Where?	Core or Sand mold dough mixing machine
5	Who?	Worker in sand preparation station
6	How?	a Poka-Yoke system with an alarm to monitor and ensure the appropriate sand composition. Providing training to workers to carry out inspections at sand preparation process

Occurrence (O), and Detection (D) values. The Severity value of 7 is due to the impact of this failure mode significantly disrupting the main product process. The Occurrence value of 6 is because this failure mode occurs relatively frequently. Meanwhile, the Detection value of 8 is due to the difficulty in detecting this composition error. Therefore, this potential failure mode is prioritized for resolution.

3.4 Improve

The improvement stage involves proposing solutions for the priority causes of defects identified in the previous stage. This stage is carried out using the 5W+1H method, as shown in **Table 3**.

3.5 Control

The control phase is the final stage in the Six Sigma method using the DMAIC approach. This phase aims to control and document the implementation of improvements made to enhance the production process of the cylinder block. In this study, the proposed improvements have not yet been implemented by the company.

4. Conclusion

The implementation of Six Sigma methodology was conducted to identify the root causes of defects in cylinder block production. A Pareto analysis revealed that "Sunakui" (sand hole) was the most prevalent type of defect, accounting for approximately 64% of total observed defects. Through a comprehensive Fishbone diagram analysis, five primary root causes were identified: unsuitable sand composition, unclear maintenance schedules, inadequate machine adjustment methods, slow pouring processes, and the absence of a method to ensure sufficient sand dryness. Failure Mode and Effects Analysis (FMEA) indicated that unsuitable sand composition had the highest Risk Priority Number (RPN), making it the most critical issue to address. To tackle these root causes, the 5W+1H (Who, What, Where, When, Why, and How) problem-solving technique was employed. This approach led to two key solutions: the installation of a Poka-Yoke system with an alarm to monitor and ensure appropriate sand composition, and the implementation of targeted training programs for workers to conduct thorough inspections during the sand preparation process.

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