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Enhancing service reliability in heavy-duty commercial vehicles industry

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ABSTRACT

Reducing breakdown lead time is a critical factor in ensuring customer productivity and sustaining competitiveness in the heavy-duty commercial vehicle (HDCV) industry. This was tackled by applying a methodology called define, measure, analyze, improve, and control (DMAIC), which stands for DMAIC. By deploying it, the breakdown lead time of an Indonesian HDCV company can be minimized. Before the initiative, the lead time was 4 days with 81.54% or 815,400 defects per million opportunities (DPMO) or less than 1 sigma with only 303 parts within target. The reduction target was 2 days as required by its customers, with 40% or 400,000 DPMO or less than 2 sigmas, with 658 parts within target. After following the methodology, the lead time was less than 2 days, meeting customer requirements with 31.2% or 312,000 DPMO, or about 2 sigmas. It shows an improved lead time, which is less than 2 days from 4 days, and a sigma level which is less than 2 sigmas from less than 1 sigma, with 908 parts within target. The study demonstrates how integrating digital applications, remanufactured spare parts, and a centralized command center significantly shortens breakdown handling.

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1. INTRODUCTION

The heavy-duty commercial vehicle (HDCV) industry plays a crucial role in supporting logistics, supply chains, and industrial productivity worldwide. Breakdowns of HDCVs result in costly downtime for customers, especially in sectors such as cold supply chains, where operational continuity is critical [1], [2]. In Indonesia, customer dissatisfaction with prolonged breakdown resolution times threatens both brand image and business sustainability. ABC is an Indonesian exclusive license agent, manufacturer, and distributor of X HDCV. The company aims to dominate its market segment in Indonesia and establish a world-class manufacturing base within its group. One of the major challenges faced by this company was frequent breakdowns of its HDCV at customer sites based on its customers' complaints. This negatively impacts the company's business sustainability and brand reputation. One of its customers has expressed concerns about how unit breakdowns would disrupt his business operations.

To address this, the company's president director emphasized the importance of delivering exceptional service to ensure customer satisfaction and uphold X brand's reputation. As stated by its director of business solutions, the primary goal is to ensure rapid and effective resolution of unit breakdowns. Thus, a dedicated innovation team from the technical warranty department of the utilization business solution division, whose roles and responsibilities include providing solutions and being problem solvers related to unit breakdown at the customer site, is formed and assigned by the company so that any unit breakdown can be rapidly solved through its dealer networks. The team needs to reduce the lead time in handling unit breakdowns. Thus, they collaborate with dealers, the truck center department, and the spare parts division to maintain customer satisfaction and loyalty effectively.

A breakdown occurred when a vehicle became inoperable [3]. It leads to financial losses due to disrupted operations. Breakdown is a condition where a vehicle undergoes a problem and cannot be used for operation, thus resulting in business loss [4]. Customers experiencing this breakdown are likely to be frustrated. Meanwhile, on the company side, the entire breakdown resolution process is estimated to take approximately 4 days, with 81.54% or 815,400 defects per million opportunities (DPMO) covering processes of problem analysis, warranty decision-making, part procurement, and part repair. Failing to address breakdowns promptly and effectively may lead to customer dissatisfaction and can jeopardize ABC's business continuity. Prolonged breakdowns can reduce customer productivity, which may result in significant financial losses. To address this, the company has instructed to reduce the lead time for breakdown resolution from 4 to 2 days with 40% or 400,000 DPMO as required by the customers.

Therefore, the team conducted a define, measure, analyze, improve, and control (DMAIC) approach under the six sigma methodology to reach customer requirements for a reduced breakdown lead time. The methodology has been widely implemented in manufacturing to improve quality and efficiency [5]. However, fewer studies have explored their application in after-sales services, particularly in vehicle breakdown management. Prior works highlight six sigma's success in healthcare services [6], IT services [7], and logistics [8], yet empirical research on after-sales service in the automotive sector remains limited. The gap addressed in this paper lies in applying the DMAIC approach to the specific challenge of reducing breakdown lead time in the HDCV sector of a developing economy. Unlike prior research that primarily focuses on manufacturing defects, this study frames lead time reduction as a service reliability improvement, integrating digital platforms, spare parts optimization, and customer engagement. There are several research questions drawn, such as: i) what theme should be defined?, ii) what is the target?, iii) what are the root causes of the gap as a problem?, iv) what are the solutions that should be addressed?, and v) how can the improvement be controlled?

Based on those research questions, 5 objectives are as follows. First, define the improvement theme. Second, set up the target. Third, analyze the root causes of prolonged breakdown lead time in HDCVs. Fourth, design and implement a DMAIC-based improvement initiative. Fifth, evaluate the operational and strategic impact of the improvement and contribute a transferable framework for after-sales service quality improvement in automotive and similar industries.

2. METHOD

The DMAIC is a systematic, data-oriented approach integral to six sigma methodologies. It is employed to enhance current business processes by eradicating defects and minimizing variability [9], [10].

i) Define: during this phase, the problem statement, project objectives, customer requirements, voice of the customer (VOC), and project scope are explicitly delineated. In this phase, instruments like the project charter and suppliers, inputs, process activities, outputs, and customers (SIPOC) diagram are commonly employed for structuring purposes. The objective is to guarantee coherence between project results and strategic business priorities [11].
ii) Measure: this phase emphasizes the collection of pertinent data to determine baseline performance and quantify the issue. A data collection plan is established, and measurement system analysis (MSA) is frequently performed to guarantee data accuracy and reliability [12]. This phase is essential for establishing an accurate comprehension of the present condition. Besides mean as an indicator, the sigma level is also commonly used.
iii) Analyze: in this phase, the team examines the data to determine the fundamental causes of variation or inefficiency using a Fishbone diagram. Statistical instruments like Pareto charts, regression analysis, and hypothesis testing are employed to ascertain cause-and-effect relationships [9]. The insights acquired serve as the foundation for focused enhancements.
iv) Improve: solutions are formulated and evaluated to tackle the identified root causes. Techniques such as brainstorming, design of experiments (DoE), and pilot studies assist in assessing the efficacy of suggested interventions [10]. The objective is to enhance the process in a regulated and verified manner.
v) Control: the concluding phase guarantees the long-term retention of the benefits derived from enhancement. This encompasses the execution of control plans, the revision of standard operating procedures (SOPs), and the utilization of statistical process control (SPC) to assess performance [11]. Training and documentation facilitate the enduring institutionalization of the new process.

Through those phases, DMAIC is inherently iterative and fosters continuous improvement, rendering it appropriate for quality management initiatives across various industries [12].

3. RESULTS AND DISCUSSION

In phase 1, namely defining, in this phase, the team collects input from customers about how the company handles customer unit breakdowns. It revealed that the customers' complaints about the prolonged breakdown resolution time are too long and are halting the business operations, thus jeopardizing the business. Therefore, the team decided that the problem statement that the team should pursue is the long unit breakdown lead time, and the project objective is to reduce its lead time. Then, the team studied the existing unit breakdown handling process at the beginning of the improvement project as part of the project scope. The process in terms of SIPOC consisted of several steps.

Firstly, the customer informs of his unit breakdown. Secondly, the dealer analyses the problem and reports to the company ABC. Thirdly, the company decides whether a guarantee can be granted or not. Finally, the dealer will follow up with part improvement before the unit is given to the customer as an operational unit. Every step needs a day to accomplish, totaling four days for the customer to wait for the unit before resuming the use of the unit. A project charter was initiated to form a dedicated innovation team from the technical warranty department of the utilization business solution division, collaborating with the dealers, the truck center department, and the spare parts division. By covering these details in the first phase, the company has guaranteed coherence between the project result and the strategic business priority.

In phase 2 of the measurement, the team established a collection plan to ensure data accuracy and reliability. Although the company has already set two days as the target required from the customer to accomplish the task, however, from data collection, it found that 1643 units in operations (UIO) from the customer side, 1,340 units, or 81.54%, were recovered in more than 2 days, or 815,400 DPMO or less than 1 sigma with 303 parts within target. This condition is extremely unacceptable for those engaged in the cold supply chain because it may jeopardize their business. Opportunity loss caused by the condition amounted to IDR 6.7 billion. From a marketing consulting firm's analysis conducted in 2022, the primary reason for the customer to select the product from the company is the efficiency of owning and operating the unit, so this problem may also affect the product's brand image. For the details, the two most important items to be improved demanded by customers are ease of availability of spare parts and low maintenance cost. Thus, the team has targeted to reduce the lead time of handling unit breakdown from four days to two days with 40% defects or 400,000 DPMO or less than 2 sigmas with 658 parts within the target.

In phase 3 analysis, to address the problem, the team begins by defining the scope, analyzing the situation, and setting targets. This is followed by a deeper root cause analysis spread across people, machines, methods, materials, and the environment (4M1E) using a fishbone diagram. From this analysis, root causes are generated and prioritized using a Pareto diagram and testing the hypothesis using regression analysis to ensure the cause-and-effect relationships as the foundation for focused enhancements, as shown in Figure 1.

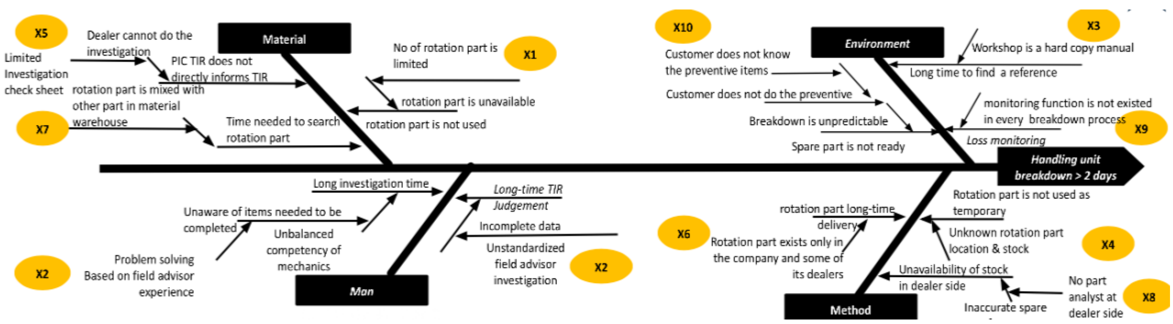

Figure 1. Fishbone diagram

On the man's side, field advisors who have responsibility for examining unit breakdown have a non-standardized investigation method (X2). It was also based on individual field advisory experience, leading to inconsistent quality and customer confusion (X2). On-ground realities further delayed the process. Field advisors have a range of levels of expertise and often seek guidance when inexperienced. The government has implemented an emission standard for Euro 4 diesel vehicles since April 12, 2022. This impacted the number of new variants and types of vehicles. It also impacted more variants of product knowledge, spare parts, and maintenance methods. Among these items, maintenance has been important to maintain vehicle performance. If it is neglected, then the unit may break down. If it is not properly handled, it may disrupt customers' business and operations, thus making them disappointed and impacting the business sustainability of the company. From the material side, the current check sheet-based analysis method proved inadequate in providing a comprehensive understanding of unit breakdown, leaving the analysis incomplete (X5). The rotation part search also lengthened the time due to the storing location, which made the rotation part mix with other materials in the material warehouse (X7). On top of that, the number of rotation parts is limited (X1). From the environment side, with only a single hard-copy workshop manual per dealer, if an advisor takes it to a customer's location, the workshop staff are left without the resources needed to do their jobs. Retrieving the necessary guidance proved to be time-consuming and frustrating (X3). Unpredictable breakdowns further complicate matters, requiring field advisors to conduct a complete problem analysis from scratch, often without any clue. This lack of preventive measures and preventive items from customers who have difficulty understanding how to handle their own unit can worsen the situation (X10). Delving into each step of the breakdown resolution process revealed a lack of monitoring (X9). From the method side, the absence of a dedicated point of contact to oversee, maintain, and facilitate the smooth handling of breakdowns throughout the process often resulted in delays in unit resolution (X8). During repairs, the spare part posed a significant obstacle. The company's rotation part program provided temporary replacements, but limited availability and a non-real-time database made timely and accurate delivery challenging (X6). Dealers struggled with access to the part stock due to its unclear part location, which worsened with limited stock availability (X4).

In phase 4 of improvement, once the root cause of the problem is identified, the team uses brainstorming techniques to formulate solutions to address the root cause. They also evaluate each solution based on its costs and benefits, ensuring it is both affordable and effective. An online voting system helps prioritize the top 10 solutions with the lowest cost and highest benefits for selection and implementation.

i) In terms of unit breakdown resolution, the team has collaborated with the procurement department to increase rotation part quantities in targeted market areas. The part is a remanufactured one from a previous part claim from its customer (S1).
ii) Another solution involves introducing fault tree analysis (FTA), a failure analysis technique, to speed up and simplify root cause identification in breakdown units (S2). This approach served as a more objective and time-efficient investigative standard. However, some breakdown cases led to the occasional oversight of the FTA form. To address this, the team transitioned to a cloud-based Google Drive system, enhancing accessibility and facilitating effective utilization of FTA in determining root causes.
iii) The team recognized the limitations of the workshop manual as the sole standardized guide for field advisors (S3). They aimed to enhance its accessibility and utilization. To do this, each dealer's workshop manual was uploaded to a cloud-based Google Drive system, facilitating easy access and simultaneous use by multiple users and streamlining problem identification. Because the drive is rarely accessed, they decided to launch an app. As an advanced improvement, the team established an application providing field advisors with a comprehensive resource for on-site issues. This integrated system consolidated valuable information, including training materials, product knowledge, spare part details, and technical problem-solving guidance. User feedback played a crucial role in the application's development, leading to the incorporation of enhanced security features, an improved search engine for easier content retrieval, and the company's product comparison tool for customer education. This helped to promote preventive measures and minimize breakdown occurrences.
iv) Each location is equipped with an autofill policy and monitoring system for real-time tracking (S4), and ninth, protection of the rotation parts in special cabinets.
v) The team decided to integrate an investigation check sheet into the logbook system [13]. This integration aimed to streamline data collection and ensure comprehensive and standardized information. The check sheet was designed by the technical information report (TIR), and new case-specific checklists were developed as needed (S5). Having to complete data made problem analysis and decision-making more efficient. Although integrating 21 checklists into the logbook system presented challenges, the team addressed these concerns by socializing with field advisors.
vi) The quantity and placement of rotation parts have been expanded to 17 dealers to ensure wider availability (S6).
vii) The team has implemented various initiatives to educate customers and minimize unit breakdowns (S7). They have developed an online maintenance guide that is easily accessible to customers through a cloud-based system. Field Advisors are responsible for explaining this guide during their monthly forums and reporting on their efforts to educate customers effectively.
viii) They have also implemented an autofill policy to restock frequently sold and transferred parts (S8). Additionally, the team has explored reconditioning reclaimed parts from customer claims as a

cost-saving and environmentally conscious initiative. Reconditioned parts undergo rigorous testing before being utilized in breakdown units.

ix) The breakdown maintenance process is monitored by the command center to detect progress in real time (S9). It was challenging to establish because it should ensure that the service and spare part teams are joined together in the center. Fortunately, with full commitment, it successfully facilitated coordination between different functions handling breakdowns and ensured a standardized flow process for efficient decision-making.

x) A centralized command center was established as a single point of control to monitor every breakdown case in real time, providing end-to-end visibility, timely escalation, and coordinated decision-making so that resolution lead time consistently meets the two-day target (S10).

In phase 5 control, after extensive efforts, the lead time for handling breakdowns was successfully reduced. By April 2023, 68.8% of unit breakdowns were resolved within the target of two days. This was only 31.2% or 312,000 DPMO, or about a 2 sigmas level. The number of cases handled within this timeframe increased by 138%, which equates to 250 more cases than targeted (from 658 to 908 within the target).

The project yielded several benefits, including cost savings from warranty claims, monitoring of manhour breakdowns, and increased profits from spare part sales, resulting in a net quality income of up to IDR 2 billion. Additionally, the company's market share saw a 1% increase, and there was a rise in workshop service revenue of IDR 1.6 billion. Furthermore, the success led to an increase in problem-handling confidence and an improvement in the brand image, resulting in the company receiving a triple star award from its headquarters in the after-sales awards. These improvements also had a positive impact on company's ecosystem, benefiting vocational schools, small and medium-sized enterprises (SMEs), and customers.

To guarantee the long-term retention of the benefits derived from the enhancement. The team encompasses the execution of control plans, the revision of SOPs, and the utilization of SPC to assess performance. Training and documentation to facilitate the enduring institutionalization of the new process are also undertaken. As a commitment to continue making further improvements, the team has decided to strengthen the command center function by integrating related systems, making the platform more impactful and powerful for the customers.

Compared to prior studies [5], this research shows that DMAIC can be extended beyond manufacturing to service ecosystems. The integration of digital tools and spare part strategies differentiates this work from earlier six sigma applications. This paper promotes several critical advancements.

i) It emphasizes supply chain resilience, highlighting how improved spare part availability reduces systemic delays and enhances overall operational efficiency. The concept of supply chain resilience is well-supported in the literature, with scholars noting that robust spare parts management mitigates risks associated with disruptions and ensures service continuity [14], [15]. These references are foundational works that discuss supply chain resilience and the importance of robust spare parts management in mitigating disruptions and maintaining service continuity. In the context of after-sales services, Antony *et al.* [5] argue that integrating digital tools into spare parts management not only streamlines inventory processes but also supports rapid response to breakdowns, further strengthening the supply chain. Enhanced spare part availability, therefore, is a key driver in minimizing lead times, improving customer satisfaction, and increasing the adaptability of service organizations to external shocks [16].

ii) It strengthens customer loyalty. Swift response times clearly signal to customers that their needs are prioritized, which helps foster trust and satisfaction. According to recent research, the adoption of digital transformation in aftersales—such as real-time tracking and automated updates—substantially enhances customers' perceptions of service reliability and efficiency [17]. Rapid and reliable customer support is a key driver in cultivating long-term customer relationships and repeat business. Empirical studies have demonstrated that organizations implementing integrated digital solutions in after-sales service operations achieve significant improvements in efficiency, customer satisfaction, and retention. For instance, integrating internet of things (IoT) and cloud-based digital platforms into spare parts and maintenance management enables real-time monitoring, predictive maintenance, and data-driven decision-making. Such digital transformation initiatives strengthen operational reliability and responsiveness, leading to enhanced customer loyalty and a sustained competitive advantage in after-sales service environments [18]–[20].

iii) It is a showcase of a service innovation. The app exemplifies digital transformation in aftersales by offering real-time appointment scheduling, automated service reminders, and personalized maintenance recommendations. These features enable faster response times, enhance customer satisfaction, and streamline service processes, making after-sales support more efficient and responsive to customer needs. Empirical research has shown that the implementation of digital platforms in after-sales and service operations enhances operational efficiency, customer satisfaction, and service quality. For example, Saccani *et al.* [21] demonstrated that integrating digital technologies such as IoT and analytics into after-sales services enables real-time monitoring, predictive maintenance, and faster response times, thereby improving customer loyalty. Similarly, Frank *et al.* [22] found that digital transformation capabilities significantly strengthen firms' operational performance and service innovation outcomes across manufacturing sectors. Building upon existing literature, recent findings by Hamid *et al.* [23] further reinforce the transformative impact of digital integration within aftersales operations. Their research highlights the effectiveness of centralized digital command centers in streamlining case management and improving real-time tracking of spare parts, which directly contributes to reducing breakdown lead times and increasing service reliability. By leveraging predictive analytics and automated communication workflows, organizations can respond to customer issues more swiftly, optimize resource allocation, and foster a culture of continuous improvement. These insights align with and extend the conclusions presented in this study, demonstrating that a holistic digital approach not only heightens operational efficiency but also enhances customer satisfaction and loyalty. Incorporating [23] strengthens the evidence supporting the scalability and adaptability of digital transformation frameworks across diverse service-intensive sectors [23].

iv) It promotes transferability. The framework's emphasis on customer engagement and process optimization makes it highly adaptable across various service-intensive industries. For instance, in healthcare, it can streamline patient care coordination and reduce wait times; in financial services, the framework can enhance client interactions and accelerate issue resolution; and in education, it could improve administrative efficiency and student support. By addressing common service delivery challenges and leveraging digital tools, the framework is well-suited to industries such as hospitality, retail, and public services, where operational reliability and customer satisfaction are critical. These concrete examples illustrate the framework's versatility and its potential to drive improvements wherever service quality and responsiveness are essential [5], [21], [22].

v) It supplies chain resilience is enhanced as spare parts become more readily available. This minimizes equipment downtime and reduces shipping delays for critical components. Increased spare part availability ensures that disruptions are addressed quickly, maintaining consistent production and service delivery while strengthening the system's ability to withstand unexpected challenges. Recent studies have shown that robust spare parts management systems, including digital inventory tracking and predictive analytics, are crucial for mitigating risks associated with supply chain disruptions and maintaining operational continuity [24], [25]. Ivanov and Dolgui [24] highlight the importance of resilient supply chain design in managing disruptions, while Tang [25] emphasizes supply chain risk management strategies that include spare parts logistics. Bode and Wagner [26] further support the role of proactive spare parts management in reducing vulnerability to unexpected events and sustaining service levels.

4. CONCLUSION

This study defined the improvement theme as reducing breakdown lead time to enhance service reliability and customer productivity in HDCV after-sales operations and set a clear target to shorten resolution time from four days to fewer than two days in line with customer requirements. Through systematic analysis, the root causes of prolonged breakdown lead time were identified, including non-standardized investigation practices, limited spare-part availability, lack of real-time visibility, fragmented cross-functional coordination, and insufficient access to technical information. A DMAIC-based improvement initiative was then designed and implemented, integrating standardized investigation tools, digital applications, optimized rotation and remanufactured spare parts, customer education, and a centralized digital command center. The results demonstrate significant operational and strategic impacts, including reduced lead time, improved service performance, financial gains, enhanced customer satisfaction, and strengthened brand image, while also contributing a transferable, digitally enabled framework for improving after-sales service quality in the automotive sector and other service-intensive industries.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Jonny	✓	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		
Januar Nasution	✓			✓				✓	✓	✓	✓	✓		

C : **C**onceptualization	I : **I**nvestigation	Vi : **Vi**sualization
M : **M**ethodology	R : **R**esources	Su : **Su**pervision
So : **So**ftware	D : **D**ata Curation	P : **P**roject administration
Va : **Va**lidation	O : Writing - **O**riginal Draft	Fu : **Fu**nding acquisition
Fo : **Fo**rmal analysis	E : Writing - Review & **E**diting	

CONFLICT OF INTEREST STATEMENT

The authors declare that there are no potential conflicts of interest with respect to the research, authorship, or publication of this article.

DATA AVAILABILITY

The datasets are available from the corresponding author, [J], upon reasonable request.

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