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Research Article

The Reduction of Paint Defects Through DMAIC Approach to Improve Product Quality in the Automotive Industry

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ABTRACT

Indonesia is one of the largest four-wheeled vehicle producers in ASEAN and has experienced rapid growth in the automotive sector. The challenge currently faced by the automotive industry is how to continuously improve product quality and reduce waste in the production process in order to remain competitive amidst the intensifying market competition. Lean Six Sigma is a systematic, data-driven methodology that combines two effective business improvement approaches to enhance product quality and reduce waste. This study applies the Lean Six Sigma framework with the DMAIC methodology to improve process quality and reduce defects in the four-wheeled vehicle assembly line. The case study was conducted at a four-wheeled vehicle manufacturer in the GIIC industrial area in Indonesia. The research began by identifying waste through value stream mapping and collecting defect data over 20 working days in October 2020. The results of the implementation showed a reduction in product defects from 2004 DPMO to 1304 DPMO, along with an improvement in the company's sigma level from 4.37 to 4.53, indicating significant improvements in both product quality and process efficiency.

1. INTRODUCTION

Indonesia is one of the largest automotive producers in the world, second only to Thailand. Several ASEAN countries, such as Indonesia, Thailand, Malaysia, and the Philippines, are known as the "ASEAN-4 cluster," and these four countries dominate the Southeast Asian market (Irawati & Charles, 2010). Indonesia has also become a vehicle exporter worldwide, making it a significant automotive producer to be reckoned with (Syah, 2019). Since 1920, Indonesia has been assembling its first vehicles, and by 2012, the country reached 1 million vehicles, making Indonesia the 17th largest vehicle producer in the world (Natsuda et al., 2013, 2015; S. Setiawan et al., 2021).

Currently, competition remains a continuous challenge for companies in the industrial sector, particularly in the manufacturing of four-wheeled motor vehicles. Motor vehicle manufacturers strive to continuously improve product quality and productivity while applying various quality management approaches, such as reducing variability and eliminating non-value-added activities (waste) in recent years (Ben Ruben et al., 2017; Chaurasia et al., 2019; Garza-Reyes et al., 2018; Makwana & Patange, 2019; Swarnakar & Vinodh, 2016; Zare et al., 2016).

The automotive industry is one of the sectors most actively involved in efforts to enhance quality, labor efficiency, and continuous improvement (Habidin, Mohd Yusof, et al., 2016; Habidin, Salleh, et al., 2016). To boost competitiveness, it is crucial to produce high-quality products by reducing waste, one of which is waste defects (Behrooz Noori, 2016). The presence of non-value-adding activities, such as waste defects, increases the need for

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labor in the rework process, making it a time-consuming and costly step that reduces process efficiency (Behrooz Noori and Mana Latifi, 2018; Boysen et al., 2009). Several studies indicate significant opportunities for improving efficiency in the automotive industry through more optimal lean management implementation (Ismail et al., 2019). Currently, Lean Six Sigma is a data-driven methodology that combines two powerful business improvement strategies, lean manufacturing and Six Sigma, with the goal of eliminating waste and reducing process variation (Ben Ruben et al., 2017; Gijo et al., 2018; Shokri, 2017; Walter & Paladini, 2019).

To eliminate waste, a systematic and easily understandable approach is required, which is lean manufacturing. One of the main tools in lean manufacturing that is widely recommended in the literature is value stream mapping, which serves to identify muda, non-value-added processes, and inefficiencies in the production line (Sisay et al., 2021). Value stream mapping is conducted using a current state map to document the production line's condition before implementing improvement techniques. Lean manufacturing is an effective method for optimizing system and production process performance because it can identify, measure, analyze, and find solutions for improvement or performance enhancement in a comprehensive manner (Jou et al., 2022; Nallusamy & Adil Ahamed, 2017).

Lean production and Six Sigma are two strategies widely adopted by companies focusing on continuous improvement (Abu Bakar et al., 2015; Albliwi et al., 2014; Salah et al., 2010). These two systems complement each other; lean production aims to improve process efficiency by streamlining production workflows and reducing waste, while emphasizing speed and efficiency. Meanwhile, Six Sigma focuses on reducing process variation to minimize product defects, with a stronger emphasis on quality improvement. Although both approaches are different in their focus on improvement, they are compatible as they both center on customer satisfaction, prioritize a process-based vision, and help reduce costs (Singh & Rathi, 2019; Yadav & Desai, 2016).

2. METHOD

The first step in implementing Lean Six Sigma is to create a current state value stream map, which aims to depict the ongoing process flow. This step is essential for understanding and identifying areas that need improvement. After obtaining an understanding of the current condition, improvements are made using the DMAIC methodology (Ben Ruben et al., 2017; Makwana & Patange, 2021; Nurcahyo et al., 2017). DMAIC, consisting of five stages—Define, Measure, Analyze, Improve, and Control—is designed to help solve problems in a structured and systematic manner. This approach allows the team to navigate the improvement process in a clear and organized way (Chaurasia et al., 2019; Jou et al., 2022; I. Setiawan & Setiawan, 2020; Swarnakar & Vinodh, 2016).

The DMAIC methodology serves as a systematic tool to drive problems toward effective solutions. Each stage in DMAIC is intended to help the team analyze the issue in greater depth, identify root causes, and find the appropriate solutions. In its implementation, it is crucial to select the right tools at each stage to support the smooth running and success of the project. Therefore, a strategic filter in choosing the appropriate tools will encourage practitioners to follow the most effective scheme throughout their projects (Behrooz Noori, 2016; Daniyan et al., 2022; Nicoletti, 2013). After the improvements have been successfully made and proven effective, the next step is to create a future state value stream map, which illustrates the process flow after the improvements are applied. This map will provide a clear picture of a more efficient and structured process. All the stages in the DMAIC methodology, along with the tools used, are clearly illustrated in Figure 1, which provides an example of how the methodology is implemented to achieve optimal results.

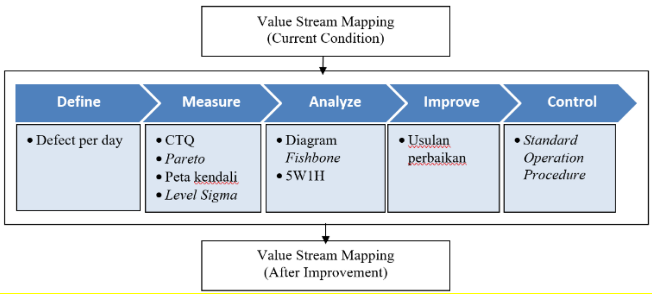

Fig 1. Research Step

The DMAIC methodology is a systematic approach used for process improvement, and each phase involves specific tools to ensure effectiveness. In the Define phase, we gather defect data, identifying areas that require attention and setting clear objectives for the project. In the Measure phase, we utilize tools such as Pareto charts and control charts to quantify the current state and determine the sigma level of the existing process, allowing us to assess performance and variation.

The Analyze phase focuses on finding the root cause of the problem. Tools like the Fishbone Diagram and 5W1H (Who, What, Where, When, Why, and How) are used to identify underlying issues, providing a structured approach to problem-solving and planning for improvements.

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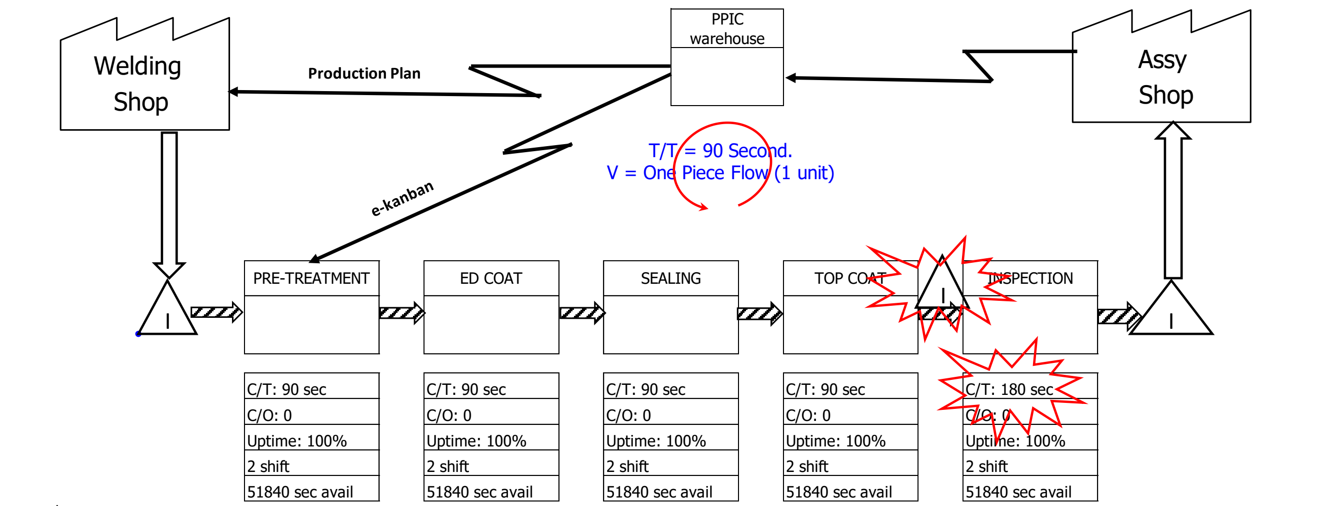
During the Improve phase, we implement solutions based on the analysis. This involves executing changes aimed at resolving the identified issues, improving efficiency and reducing defects in the process. Finally, in the Control phase, we establish activities to maintain the improvements and ensure that the issues do not recur. This phase often includes monitoring tools and setting up control plans to track process performance over time and sustain the gains achieved through the DMAIC process. Each phase builds on the previous one, ensuring a continuous improvement cycle.

3. RESULT AND DISCUSSION

This case study was conducted by the researcher due to the presence of waste in the paint production line for four-wheeled vehicles. The high number of defects detected during the paint inspection process, where inline repairs are needed, results in longer repair times compared to the customer demand time (takt time). This is caused by the large quantity and variability of defects caught during the inspection. Complaints from the inspection department regarding these defects lead to an increase in non-value-adding activities, which in turn raises rework times and costs that the company must bear, such as additional manpower, material replacement costs, and delayed shipments. Waste identification can be observed in Figure 2.



L/T Process			90		90		90		90		180			540.00
L/T Conveyance		300		0		0		0		0		0		300.00
L/T Stagnation	7200	0		0		0		0		180		0	14400	21780.00
											Total Lead Time (second)			**22620.00**
											Total Lead Time (Hours)			**6.283333**

Fig. 2. Value Stream Mapping (Current Condition)

Looking at the current condition value stream mapping, we can identify an issue (explosion diagram), which is a bottleneck in the vehicle cabin before entering the inspection area due to the difference in cycle time between the previous TOPcoat process, which has a cycle time of 90 seconds, and the inspection cycle time of 180 seconds. This issue is caused by the high number of defects caught at the inspection station, which results in the inspection process taking longer than the production takt time. To address the paint inspection issue, corrective actions have been taken to reduce defects by utilizing the DMAIC approach (Define, Measure, Analyze, Improve, and Control).

Define

The Define phase is the first operational step in the quality improvement program within Six Sigma. This phase involves defining several aspects related to the criteria for selecting the defect products to be studied. The project selection criteria in this research prioritize recurring issues. Based on this consideration, the study was conducted on the paint production line of four-wheeled vehicles. The project was chosen due to the discovery of defects in the vehicles, which disrupt the paint production line such as dust seed, popping, selant damage, runs paint, sanding mark, thin paint, crater, etc. Below is the appearance defect data from the assembly of four-wheeled vehicles at an automotive manufacturer in Indonesia during August 2024.

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Tabel 1. Defect Data

Day to	Production Volume	Defect
1	680	13
2	680	7
3	680	19
4	680	6
5	690	18
6	680	19
7	680	13
8	680	4
9	690	17
10	680	6
11	680	3
12	680	5
13	680	14
14	690	12
15	680	6
16	680	10
17	680	13
18	690	16
19	690	12
20	690	6
Total	13,660	219

Measure

In this phase, measurements are taken on the types of defects that have been identified. To determine these measurements, key characteristics critical to quality (CTQ) will be established, and the sigma level will be calculated based on the defects per million opportunities (DPMO). The determination of Critical to Quality (CTQ) is based on the specific needs of the customer. The selection of these CTQs is made from the defects that have the most significant impact on product quality. The priority defects, which account for the cumulative 80%, will be the main issues addressed. According to the Pareto diagram (Figure 3), the largest defects requiring corrective action are Dust Seed (42%), Popping (31%), and Sealant Damage (15%). These three defects together account for 88%, in line with the Pareto principle (80:20). Therefore, these CTQs have a significant impact on product quality and will be addressed in the Six Sigma project. The study will focus solely on the largest defect, Dust Seed.

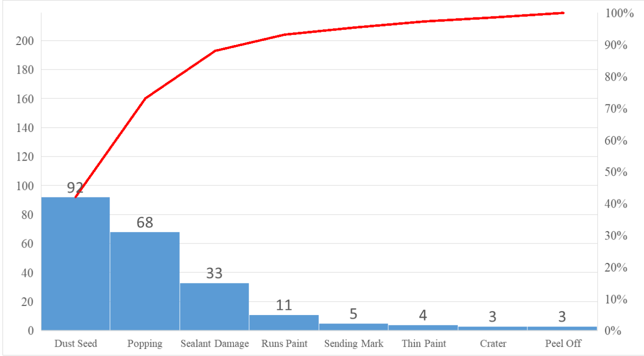

Fig. 3. Pareto Diagram

The Dust Seed defect on a vehicle's paint surface is a type of flaw caused by dust particles or small debris left on the paint surface during the painting process. These dust particles can originate from the surrounding environment or from the painting process itself, such as during the application of paint or drying. When the dust adheres to a surface that is still wet or partially dry, it can create small spots that appear like "dust seeds" on the completed paint surface. This defect can affect the vehicle's visual appearance, as the dust causes unevenness in the paint layer, making the surface look rough or dirty. The Dust Seed defect can be seen in Figure 3.

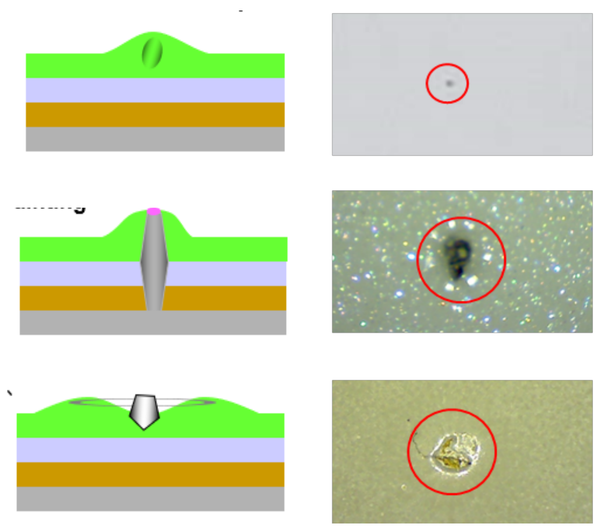

Fig. 3. Dust Seed Defect

After Dust seed becomes the priority defect to address, the next step is to check whether the defect proportion is acceptable or not in the control chart. The control chart used is an attribute control chart because the quality characteristics cannot be presented in numerical form but can only be categorized into specific groups, such as defective or non-defective, conforming or non-conforming to specifications, and pass or fail. Therefore, data like this is classified as attribute data. The chart used is the p-chart because the p-chart is applied when the defect measure is expressed as the proportion of defective

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products in each sample taken, with the number of samples varying each time an observation is made..

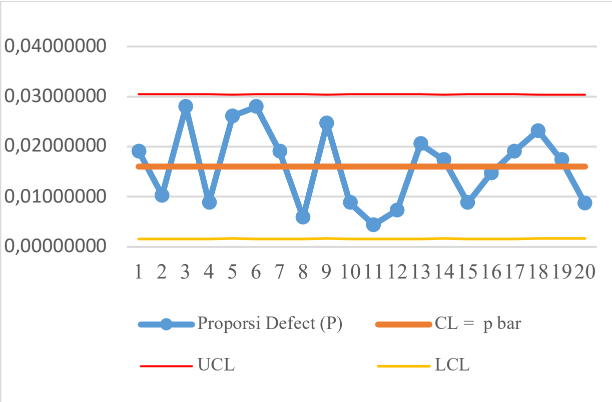

Fig. 4. Dust Seed P-chart

The measurement results in the form of attribute data will be evaluated based on performance using the DPMO (Defects per Million Opportunities) unit. To calculate DPMO, data such as opportunities (OP), defects (D), defects per unit (DPU), total opportunities (TOP), and defects per opportunity (DPO) are required. The results of this defect calculation can be seen in Table 2.

Tabel 2. DPMO Defect

Criteria	Numbers
Production Volume	13660
Opportunities (OP)	8
Defect (D)	219
Defect per Unit (DPU)	0.016032
Total Oportunities	109280
Defect Per Oportunities	0.002004
Defect Per Million Oportunities	2004.026
Sigma Level	4.3725

Based on the data processing results that have been conducted, the DPMO value in Aug 2024 is 2004.026, and the company's sigma level remains at 4.37. This indicates that while the company has made progress, there is still room for improvement in its processes to achieve higher efficiency and quality.

Analyze

In the analysis phase, it is essential to identify the root cause of the issue before executing any corrective actions, using a fishbone diagram. The researcher conducted a focus group discussion for brainstorming with employees to determine the root causes of the numerous Dust seed defects. The results of the brainstorming session are presented in the fishbone diagram, as shown in Figure 5.

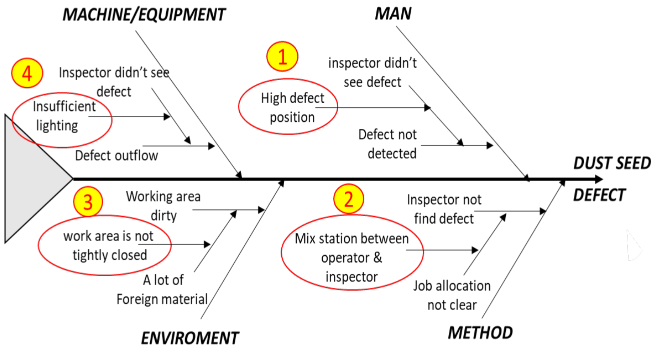

Fig. 5. Fishbone Diagram

From the results of this fishbone analysis, we identified potential root causes stemming from four factors: man, machine, method, and environment. These factors play a critical role in the overall process, and understanding them will allow for targeted improvements to enhance efficiency and product quality across various departments.

Improve

Based on the fishbone diagram, improvements can be made to the four-wheeled motor vehicle defects using the 5W+1H method, which is an approach for developing repair plans and enhancing quality. The quality improvement plan for the dust seed defect type can be seen in Table 3.

Table 3. 5W1H

Factor	What	Why	How	Where	Who	When
Man	High defect position	Many defect come from roof area	Making a foothold for the inspector	Paint Inspection	Mr Albi	3-Sep
Method	Mix station between operator & inspector	Job alocation not clear	Arrange a separate station for inspection	Paint Inspection	Mr. Soni	15-Sep
Machine/ equipment	Insufficient lighting	Small dust seed defects are hard to see	Addition of lights for checking	Paint Inspection	Mr Beni	15-Sep
Environment	Work area is not tightly closed	Wrong building specification for paint	Build a clean room for preparation station of plastic parts	Paint Inspection	Mr. Ajo	30-Sep

Based on the improvement plan in 5W1H, improvements are made according to the plan that has been developed. This plan will have a significant impact on reducing defects and accelerating the inspector's inspection time.

For the first improvement, calculate the average height of the inspector and compare it with the height of the vehicle, figure 6. The goal is for the inspector to be able to reach all surfaces of the vehicle from bottom to top so that it is easy to find defects that occur.

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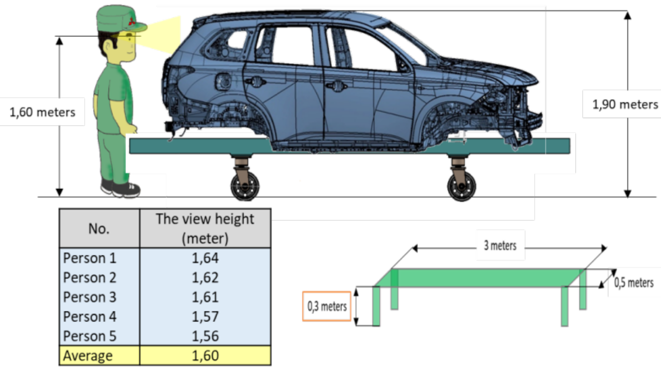

No.	The view height (meter)
Person 1	1,64
Person 2	1,62
Person 3	1,61
Person 4	1,57
Person 5	1,56
Average	1,60

Fig. 6. Compare Between Inspector vs Vehicle.

From the calculation of the average inspector height, a platform was created for the operators so they can reach all areas during inspections, as shown in Figure 7. This adjustment ensures that inspectors can perform their tasks efficiently and thoroughly, improving overall inspection quality and reducing the potential for overlooked defects.

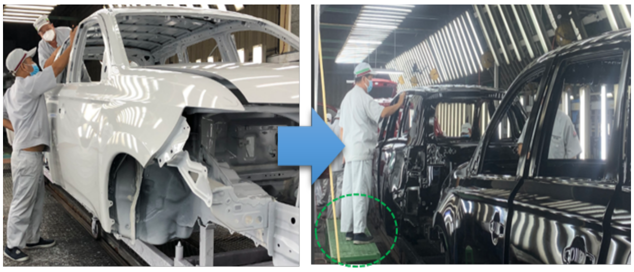

Fig.7. Before & After Improvement

The second improvement is related to the method factor. The inspection process consists of polishing and inspection processes. Previously, the job allocation and workstations between the process operators and inspectors were combined. In the previous setup, one inspector checked the first and second vehicles for both the right and left sides, with a total of 2 inspectors (green) and 6 polishing operators (yellow). After implementing the improvement in job allocation by separating the polishing workstations and inspectors, we were able to reduce the manpower in the inspection area from 8 people to 6 people. The results before and after the job allocation can be seen in Figure 8.

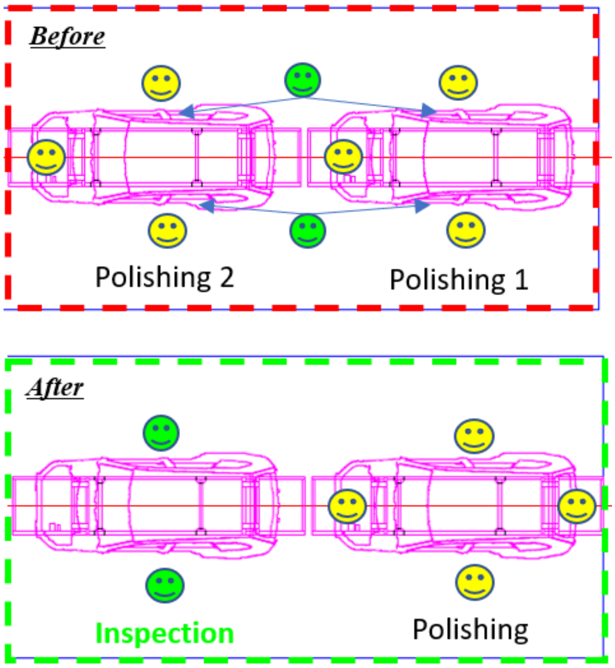

Fig. 8. Job Alocation Improvement

The third improvement is to cover all ventilation gaps with plastic so that dust does not enter the painting process. (figure 9)

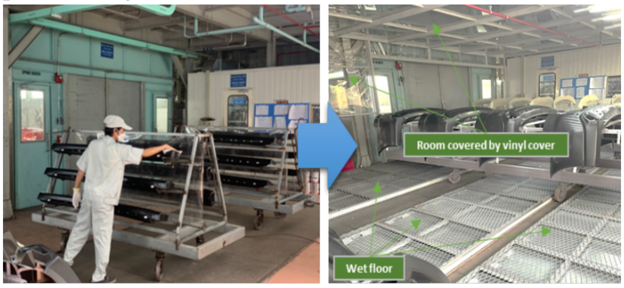

Fig. 9, Before & After Improvement

The Fourth improvement is the addition of lights to help inspectors easily detect small and fine dust seed defects. This enhancement ensures that inspectors can spot even the most minor issues more effectively, leading to higher accuracy in identifying defects and improving overall product quality (figure 10)

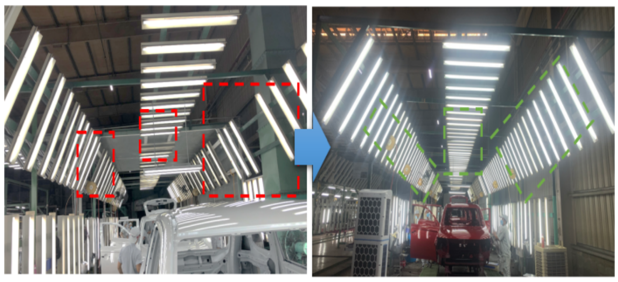

Fig. 10. Before & After Improvement

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Control

The control phase is the final stage in the Six Sigma quality improvement method. In this phase, the improvements are monitored to determine whether the production process has improved after the implementation. Additionally, it assesses whether the DPMO (Defects Per Million Opportunities) has decreased and whether the sigma level has increased following the implementation. The defect data after the improvements were collected again in November 2024, as shown in Figure 11.

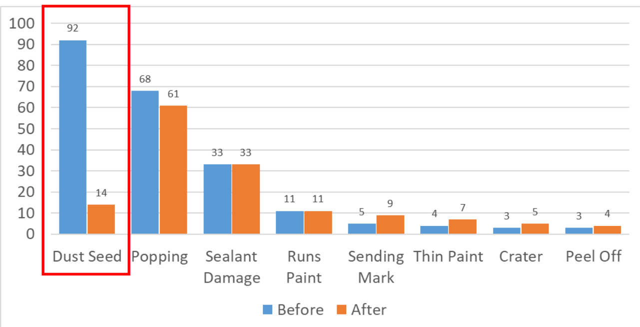

Fig. 11. Defect reduction before and after

This comparison is conducted to determine whether the DPMO after the improvements has decreased compared to the DPMO before the improvements, while the Sigma Level has increased following the implementation of improvement efforts in the process. The DPMO values and Sigma Levels before and after the improvements can be seen in Table 4.

Tabel 4. Comparison of DPMO and Sigma

Criteria	Before	After
DPMO	2004	1304
Sigma Level	4,37	4,53

Based on Table 4, it is evident that the DPMO decreased after the improvements were implemented. The reduction in DPMO after the improvements is 1304, while the increase in the Sigma Level is 4.53.

The results of the defect reduction activities for Dust Seed using the DMAIC methodology have led to a decrease in cycle time during the inspection process. In this inspection process, fewer defects were found, allowing the polishing process to be completed much more quickly. As a result, the inspection cycle time has been reduced from 180 seconds to approximately 88 seconds. If the inspection process time is reduced, the overall Paint production line can operate smoothly without bottlenecks, enabling a more efficient workflow. Additionally, this improvement helps in reducing inventory levels before the inspection process, optimizing resource utilization, improving production efficiency, and enhancing overall product quality. By minimizing bottlenecks and streamlining inspection, the manufacturing process becomes more cost-effective, leading to increased productivity and better operational performance. The value stream mapping after the improvements can be seen in Figure 12.

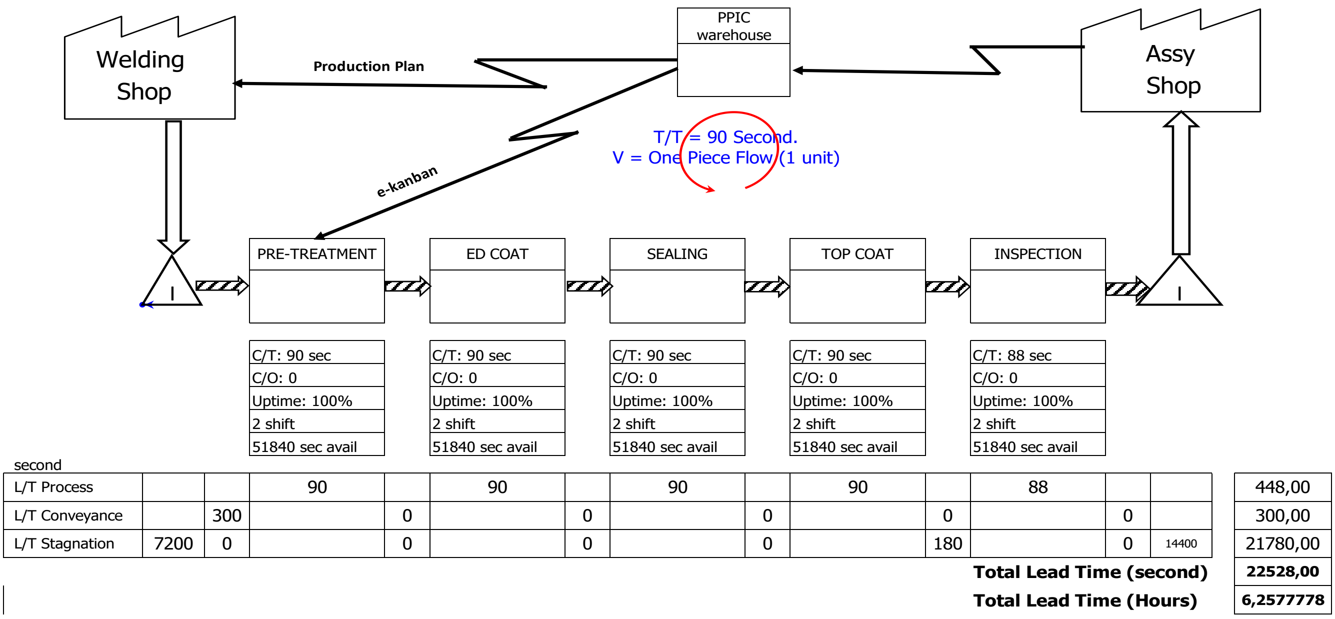

Fig. 12. Value Stream Mapping (After Improvement)

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4. CONCLUSION

The study began with a value stream mapping analysis, which revealed that the inspection process faced significant challenges. One of the main issues was that the inspection cycle time was longer than the takt time, causing the inspection process to become a bottleneck in the value stream of the Paint production line. This hindered overall production efficiency and led to an increase in inventory levels before the inspection process. Therefore, the DMAIC (Define, Measure, Analyze, Improve, Control) approach was implemented to systematically address this issue.

Through an analysis of the Man, Machine, Method, and Environment factors, this study successfully identified a solution to reduce Dust Seed defects. As a result of the improvements made, the number of Dust Seed defects was reduced from 219 units to 144 units. This defect reduction contributed to a decrease in the Defects Per Million Opportunities (DPMO) value from 2004 to 1304. Additionally, this quality improvement was also reflected in an increase in the sigma level, which improved from 3.52 to 4.37.

The impact of these improvements not only enhanced product quality but also improved overall production efficiency. With fewer defects and a shorter inspection time, the production flow became smoother without significant bottlenecks. This also allowed the company to reduce inventory levels before inspection, ultimately lowering production costs and increasing productivity.

In the future, this study can be further developed to achieve a higher sigma level by addressing other defects that still occur in the production process. Based on Pareto analysis, the next significant defect is Popping, which is caused by trapped air on the paint surface. Therefore, improvement efforts can focus on controlling environmental conditions during the painting process and enhancing technology in paint application processes.

Furthermore, this research can also be expanded through a digital approach to enhance the accuracy and efficiency of inspections. One possible innovation is the implementation of AI-based camera technology capable of detecting defects in real time. With this technology, the inspection process can be conducted more quickly and accurately, allowing for a faster response to defects within the production line.

REFERENCES

Abu Bakar, F. A., Subari, K., & Mohd Daril, M. A. (2015). Critical success factors of Lean Six Sigma deployment: a current review. *International Journal of Lean Six Sigma*, *6*(4), 339–348. https://doi.org/10.1108/IJLSS-04-2015-0011

Albliwi, S., Antony, J., Lim, S. A. H., & van der Wiele, T. (2014). Critical failure factors of lean Six Sigma: A systematic literature review. *International Journal of Quality and Reliability Management*, *31*(9), 1012–1030. https://doi.org/10.1108/IJQRM-09-2013-0147

Behrooz Noori and Mana Latifi. (2018). Development of Six Sigma methodology to improve grinding processes : a change management approach Article information : About Emerald www.emeraldinsight.com. *International Journal of Lean Six Sigma*, *9*(1), 50–63.

Behrooz Noori, M. L. (2016). *International Journal of Lean Six Sigma Development of Six Sigma methodology to improve grinding processes : a change management approach Article information : About Emerald www.emeraldinsight.com*.

Ben Ruben, R., Vinodh, S., & Asokan, P. (2017). Implementation of Lean Six Sigma framework with environmental considerations in an Indian automotive component manufacturing firm: a case study. *Production Planning and Control*, *28*(15), 1193–1211. https://doi.org/10.1080/09537287.2017.1357215

Boysen, N., Fliedner, M., & Scholl, A. (2009). Sequencing mixed-model assembly lines: Survey, classification and model critique. *European Journal of Operational Research*, *192*(2), 349–373. https://doi.org/10.1016/j.ejor.2007.09.013

Chaurasia, B., Garg, D., & Agarwal, A. (2019). Lean Six Sigma approach: A strategy to enhance performance of first through time and scrap reduction in an automotive industry. *International Journal of Business Excellence*, *17*(1), 42–57. https://doi.org/10.1504/IJBEX.2019.096903

Daniyan, I., Adeodu, A., Mpofu, K., Maladzhi, R., & Kana-Kana Katumba, M. G. (2022). Application of lean Six Sigma methodology using DMAIC approach for the improvement of bogie assembly

 DOI: 10.52330/jtm.v23i1.418

process in the railcar industry. *Heliyon*, *8*(3), e09043. https://doi.org/10.1016/j.heliyon.2022.e09043

Garza-Reyes, J. A., Kumar, V., Chaikittisilp, S., & Tan, K. H. (2018). The effect of lean methods and tools on the environmental performance of manufacturing organisations. *International Journal of Production Economics*, *200*(March), 170–180. https://doi.org/10.1016/j.ijpe.2018.03.030

Gijo, E. V, Palod, R., & Antony, J. (2018). The Management of Operations Lean Six Sigma approach in an Indian auto ancillary conglomerate : a case study Lean Six Sigma approach in an Indian auto ancillary conglomerate : a case study. *Production Planning & Control*, *7287*(May), 1–12. https://doi.org/10.1080/09537287.2018.1469801

Habidin, N. F., Mohd Yusof, S., & Mohd Fuzi, N. (2016). Lean Six Sigma, strategic control systems, and organizational performance for automotive suppliers. *International Journal of Lean Six Sigma*, *7*(2), 110–135. https://doi.org/10.1108/IJLSS-04-2015-0013

Habidin, N. F., Salleh, M. I., Md Latip, N. A., Azman, M. N. A., & Mohd Fuzi, N. (2016). Lean six sigma performance improvement tool for automotive suppliers. *Journal of Industrial and Production Engineering*, *33*(4), 215–235. https://doi.org/10.1080/21681015.2015.1136966

Irawati, D., & Charles, D. (2010). The involvement of Japanese MNEs in the Indonesian automotive cluster. *International Journal of Automotive Technology and Management*, *10*(2–3), 180–196. https://doi.org/10.1504/IJATM.2010.032623

Ismail, M. Z. M., Zainal, A. H., Kasim, N. I., & Mukhtar, M. A. F. M. (2019). A mini review: Lean management tools in assembly line at automotive industry. *IOP Conference Series: Materials Science and Engineering*, *469*(1). https://doi.org/10.1088/1757-899X/469/1/012086

Jou, Y. T., Silitonga, R. M., Lin, M. C., Sukwadi, R., & Rivaldo, J. (2022). Application of Six Sigma Methodology in an Automotive Manufacturing Company: A Case Study. *Sustainability (Switzerland)*, *14*(21), 1–27. https://doi.org/10.3390/su142114497

Makwana, A. D., & Patange, G. S. (2019). A methodical literature review on application of Lean & Six Sigma in various industries. *Australian Journal of Mechanical Engineering*, *00*(00), 1–15. https://doi.org/10.1080/14484846.2019.1585225

Makwana, A. D., & Patange, G. S. (2021). A methodical literature review on application of Lean & Six Sigma in various industries. *Australian Journal of Mechanical Engineering*, *19*(1), 107–121. https://doi.org/10.1080/14484846.2019.1585225

Nallusamy, S., & Adil Ahamed, M. A. (2017). Implementation of lean tools in an automotive industry for productivity enhancement - A case study. *International Journal of Engineering Research in Africa*, *29*, 175–185. https://doi.org/10.4028/www.scientific.net/JERA.29.175

Natsuda, K., Otsuka, K., & Thoburn, J. (2015). Dawn of Industrialisation? The Indonesian Automotive Industry. *Bulletin of Indonesian Economic Studies*, *51*(1), 47–68. https://doi.org/10.1080/00074918.2015.1016567

Natsuda, K., Segawa, N., & Thoburn, J. (2013). Liberalization, Industrial Nationalism, and the Malaysian Automotive Industry. *Global Economic Review*, *42*(2), 113–134. https://doi.org/10.1080/1226508X.2013.791475

Nicoletti, B. (2013). A Comprehensive Insight Into The Six Sigma DMAIC Toolbox. *International Journal of Lean Six Sigma*, *4*(2), 184–203.

Nurcahyo, R., Apdillah, R., & . Y. (2017). Application of Lean Six Sigma and Theory of Inventive Problem Solving to Reduce Waste and Improve the Quality Motorcycle Rear Arm. *Journal of Asian Scientific Research*, *7*(5), 176–186. https://doi.org/10.18488/journal.2.2017.75.176.186

Salah, S., Rahim, A., & Carretero, J. A. (2010). The integration of Six Sigma and lean management. In *International Journal of Lean Six Sigma* (Vol. 1, Issue 3). https://doi.org/10.1108/20401461011075035

Setiawan, I., & Setiawan, S. (2020). Defect reduction of roof panel part in the export delivery process using the DMAIC method: a case study. *Jurnal Sistem Dan Manajemen Industri*, *4*(2), 108–116. https://doi.org/10.30656/jsmi.v4i2.2775

Setiawan, S., Setiawan, I., Jaqin, C., Prabowo, H. A., & Purba, H. H. (2021). Integration of waste assessment model and lean automation to improve process cycle efficiency in the automotive industry. *Quality Innovation Prosperity*, *25*(3), 48–64. https://doi.org/10.12776/qip.v25i3.1613

Shokri, A. (2017). Quantitative analysis of Six Sigma, Lean and Lean Six Sigma research publications in last two decades. *International Journal of Quality and Reliability Management*, *34*(5), 598–625. https://doi.org/10.1108/IJQRM-07-2015-0096

Singh, M., & Rathi, R. (2019). A structured review of Lean Six Sigma in various industrial sectors. In *International Journal of Lean Six Sigma* (Vol. 10, Issue 2). https://doi.org/10.1108/IJLSS-03-2018-0018

Sisay, G., Kitaw, D., Ebinger, F., & Jilcha, K. (2021). Developing Integrated Continuous Improvement Model for Competitiveness of Ethiopian Automotive Industry. *European Online Journal of Natural and Social Sciences*, *10*(2), 223–247. http://www.european-science.com

Swarnakar, V., & Vinodh, S. (2016). Deploying Lean Six Sigma framework in an automotive component manufacturing organization. *International Journal of Lean Six Sigma*, *7*(3), 267–293. https://doi.org/10.1108/IJLSS-06-2015-0023

Syah, D. O. (2019). Identifying vertical partnership among automotive component companies: empirical evidence from automotive industry in Jabodetabek, Indonesia. *Journal of Economic Structures*, *8*(1). https://doi.org/10.1186/s40008-019-0149-z

Walter, O. M. F. C., & Paladini, E. P. (2019). Lean Six Sigma in Brazil: a literature review. In *International Journal of Lean Six Sigma* (Vol. 10, Issue 1). https://doi.org/10.1108/IJLSS-09-2017-0103

Yadav, G., & Desai, T. N. (2016). Lean Six Sigma: a categorized review of the literature. *International Journal of Lean Six Sigma*, *7*(1), 2–24. https://doi.org/10.1108/IJLSS-05-2015-0015

Zare, M., Croq, M., Hossein-Arabi, F., Brunet, R., & Roquelaure, Y. (2016). Does Ergonomics Improve Product Quality and Reduce Costs? A Review Article. *Human Factors and Ergonomics In Manufacturing*, *26*(2), 205–223. https://doi.org/10.1002/hfm.20623