Enhancing Automotive Part Quality in SMEs through DMAIC Implementation: A Case Study in Indonesian Automotive Manufacturing

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ABSTRACT

Purpose: This study aims to reduce defects and improve the quality of automotive parts at SMEs by implementing the define, measure, analyse, improve, and control (DMAIC) stage of Six Sigma.

Methodology/Approach: The application of the DMAIC method was carried out in an automotive component manufacturing company in Indonesia that produces Stay B Muffler Protector HC21 as a research object. The cause of the high number of product defects is known at the define stage. In the measure stage, details from field data are collected, and sigma levels are determined.

Findings: The improvement actions results impact the DPMO value and an increase in the sigma level. DPMO value decreased by 19,891 from 22,230 to 2,339. Meanwhile, the sigma level increased by 0.82 from 3.51 to 4.33. In controlling the sigma level, improvements should be made by creating work instructions for the use of spot welding equipment so that everything can be standardised so that it can be controlled continuously and make continuous improvements.

Research Limitation/implication: Limitations of this study may include limitations in covering all aspects of production or other factors that may affect product quality.

Originality/Value of paper: This paper's originality lies in applying the DMAIC method of Six Sigma in the context of automotive manufacturing SMEs in Indonesia.

Category: Case study

Keywords: automotive parts; DMAIC; quality; Six Sigma

1 INTRODUCTION

The manufacturing industry is essential to the Indonesian economy (Silalahi, 2014). Every business actor in this field competes to produce the highest quality products. Products with good quality and low prices can provide customer satisfaction (Razak and Nirwanto, 2016; Amini and Wiranatakusuma, 2020) and can become a strategy in national and international competition (Mantrala et al., 2006; Stylidis, Wickman and Söderberg, 2015). Getting goods with the best quality and prices that can compete in the market is demanding.

Companies need an excellent strategy to reduce production costs without reducing the quality of goods. One strategy that can be applied is to minimize errors in the production line (Karthik, Halesh and Hanumanthrayagouda, 2019; Sumasto, Satria and Rusmiati, 2022; Sumasto et al., 2023a). The excellent strategy can be applied by producing goods with zero defects (Nallusamy et al., 2018; Sumasto et al., 2023b) or choosing raw material suppliers at affordable prices and with good quality. In this case, the production department in a manufacturing company plays a vital role in continuously increasing the effectiveness and productivity of the production process of an item. The production department depends on the workforce, the tools/machines that are operating, and the raw materials used to maintain quality with a minimum defect rate.

Companies in the manufacturing sector have the potential to produce high-defect products (Lin, Chen and Xie, 2012; Bebeteidoh and Takim, 2015). This potential is detrimental to the company in terms of time and cost because any defects produced cannot be used or repaired. This potential problem also occurs in Automotive SMEs, where there is a part that has the highest defect rate every day, namely the Stay B Muffler Protector HC21 part (Fig. 1). Based on the daily inspection report of Automotive SMEs, the Stay B Muffler Protector HC21 part in each final inspection process found a part that did not meet the specifications (part NG). Parts found to be different from specifications will go through a repair process. This process is carried out by the operator one by one. Based on this, it is a waste of time because the number of NG parts that go into the repair process is at least more than 50 pcs.

Figure 1 – Stay B Muffler Protector HC21

Based on the problems faced by the company, improvements are needed to minimise defects using a Six Sigma approach, which consists of five stages. These stages are known as DMAIC, which stands for each stage: define, measure, analyse, improve, and control. This method is expected to minimise the number of defective product Parts Stay B Muffler Protector HC21 at Automotive SMEs.

2 LITERATURE REVIEW

During the increasingly fierce global competition, the manufacturing industry strives to improve product quality, production efficiency, and customer satisfaction (Rifqi et al., 2021; Duc, Bilik and Truong, 2022; Gomes et al., 2022). Lean Manufacturing and Six Sigma concepts have emerged as practical approaches to achieving these goals in this endeavour. One approach often used is DMAIC (Define-Measure-Analyze-Improve-Control), a framework for systematically directing process improvement. The application of DMAIC in Lean Manufacturing, especially in the automotive industry context, is an alternative to improve product quality (Rifqi et al., 2021; Condé et al., 2023).

One of the main themes emerging from previous research is increasing production efficiency and reducing product defects. In case studies in automotive companies, DMAIC is used to improve production flow by reducing waste and minimising defects. The results of implementing DMAIC are seen in better production planning, increased smooth production flow, and significant financial benefits for the company (Condé et al., 2023; Sharma et al., 2023). Another significant theme is post-sales process optimisation through the DMAIC approach. In the automotive industry, applying DMAIC helps reduce the average service time in the workshop, reduce material waste, and increase customer satisfaction (Subburaj, Prabhakaran and Prabhuram, 2010). These studies also highlight the application of Six Sigma and DMAIC in improving product quality. DMAIC reduces defect rates in manufacturing processes, focusing on improving Sigma level and process capability (Ruben, Vinodh and Asokan, 2017). This theme is also found in research discussing the application of Lean Six Sigma in automotive assembly plants to reduce non-value-added processes in assembly lines (Brun and Milano, 2014). In addition to operational benefits, DMAIC has also been used in environmental contexts. Research shows that integrating Lean Six Sigma can help reduce the consumption of raw materials, energy, and waste, resulting in a lower environmental impact (Sharma, Gupta and Saini, 2018; Neeru, Rajput and Patil, 2023).

From an analysis of previous studies discussing the application of DMAIC in Lean Manufacturing, the DMAIC approach positively impacts production efficiency, reduces product defects, improves product quality, and even reduces environmental impact. Integrating Lean Six Sigma and DMAIC proves that this approach can provide multiple benefits for companies regarding operational and environmental responsibility. Therefore, DMAIC has become essential in achieving improvement goals in the modern manufacturing industry (Kosina, 2015), especially in the automotive sector.

3 RESEARCH METHODS

This research was conducted based on the Six Sigma approach using DMAIC, which needs to fulfil 5 (five) stages: Define, Measure, Analyze, Improve, and Control. The define stage defines the problems obtained from processing production data at Automotive SMEs, including data defects on the Stay B Muffler Protector part from September 2022 to November 2022. At this stage, the problems are determined by selecting projects to improve quality, identifying SIPOC diagrams, making Pareto diagrams to find out the most significant impact of defects, and identifying Critical to Quality (CTQ) (Sumasto, Satria and Rusmiati, 2022). The measuring stage is carried out to calculate the proportions, create a P-control chart, calculate the Defects Per Million Opportunities (DPMO), and the initial sigma level as a baseline (Daniyan et al., 2022).

The analysis, improvement, and control stages are carried out in the analysis and discussion of the results. The analysis phase is carried out to determine the problem's root by using a fishbone diagram. Next, identify the factors causing the problem and re-analyze using 5W+1H to produce a proposed improvement plan (Henny et al., 2019; Pereira et al., 2019; Guleria et al., 2020). In the improvement stage, improvements are implemented based on the analysis results and calculating DPMO and sigma level after improvement. At the control stage, measurement and evaluation of the stability of the production process is carried out again using a P-control chart, and standardisation is carried out by making work instructions.

4 RESULTS AND DISCUSSION

4.1 Define Stage

The define stage begins with identifying the problems that occur so that they can be overcome. Problems that occur are based on identification results in the field and looking at the SIPOC diagram (Fig. 2) as well as inspection data and the number of defects for the Stay B Muffler Protector HC21 product in September-November 2022, there are 2260 pcs defects or 7.21% of total production. Based on this, the Stay B Muffler Protector HC21 defect data is classified according to the type of defect from the CTQ (Fig. 3) and is made in a Pareto diagram (Fig. 4) to see the impact of the the most significant defect.

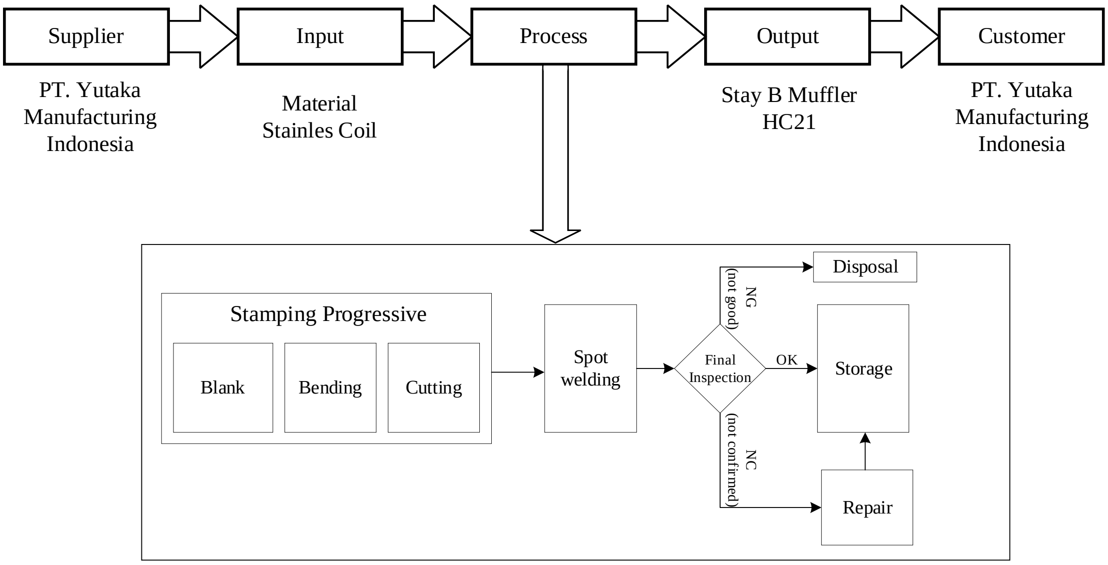

Figure 2 – SIPOC diagram of Stay B Muffler Protector HC21

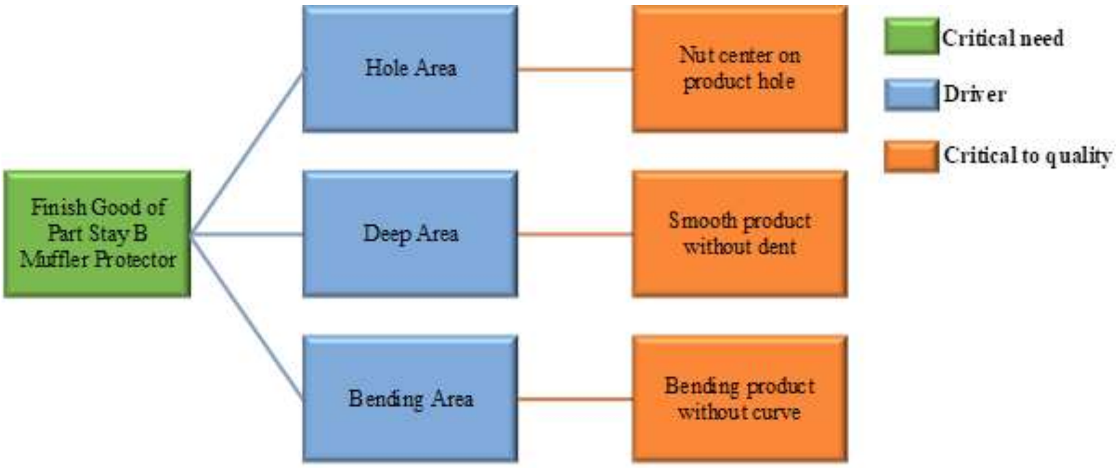

Figure 3 – CTQ on Stay B Muffler Protector HC21

Based on the Pareto diagram of the percentage of product defects in Stay B Muffler Protector HC21 (Fig. 4), It can be seen that the highest type of defect found in the product is a defect in the Non-Center Hole Position with a total percentage of 86.5%. Types of defects Non-Center Hole Position are the focus/priority of the improvements in this study, where these defects originate from the spot welding process.

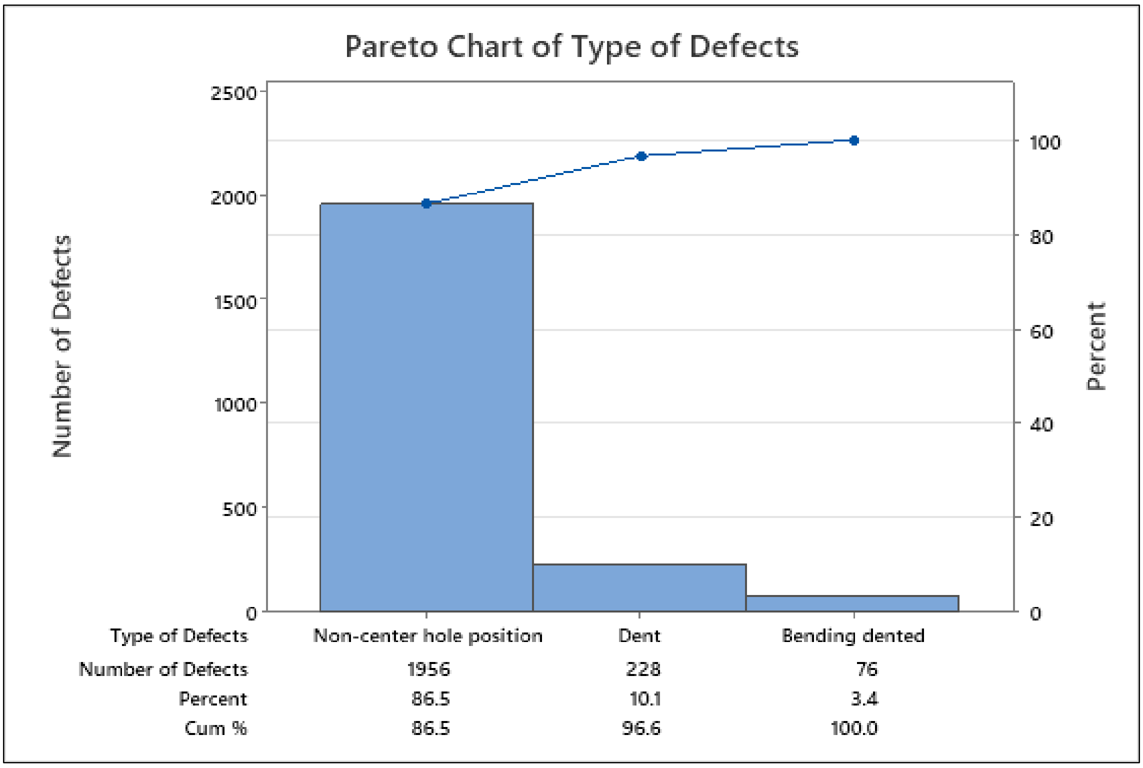

Figure 4 – Pareto diagram of Stay B Muffler Protector HC21

4.2 Measure Stage

The measure stage is the second stage in the Six Sigma method. At this stage, the P-control chart will be made, calculating the DPMO (Defect Per Million Opportunity) and the Sigma Level the company has achieved and calculating the DPMO and Sigma Level the company wants to achieve. The P-control chart for attribute data helps measure and monitor the number of defects or quality failures in a process. Using the P-control chart for attribute data at the DMAIC Measure stage makes it possible to understand process quality better, identify deviations, and take the necessary actions to improve and control product quality. Data for P-control chart from inspection results data from September to November 2022 (Tab. 1). Based on Fig. 5, all data is at the control limit where no data comes from the UCL or LCL.

Table 1 – Calculation of P-control chart on Defect Non-Center Hole Position

No	Date	Production (pcs)	Number of Defects *(pcs)*	Proportion	CL	UCL	LCL
1	12-Sep-22	3200	195	0.0609	0.0667	0.0799	0.0535
2	16-Sep-22	2000	130	0.0650	0.0667	0.0834	0.0500
3	19-Sep-22	3600	228	0.0633	0.0667	0.0792	0.0542
4	23-Sep-22	3700	235	0.0635	0.0667	0.0790	0.0544
5	04-Oct-22	200	12	0.0600	0.0667	0.1196	0.0138

No	Date	Production (pcs)	Number of Defects *(pcs)*	Proportion	CL	UCL	LCL
6	06-Oct-22	1600	124	0.0775	0.0667	0.0854	0.0480
7	07-Oct-22	600	48	0.0800	0.0667	0.0972	0.0361
8	12-Oct-22	2900	210	0.0724	0.0667	0.0806	0.0528
9	14-Oct-22	1000	82	0.0820	0.0667	0.0904	0.0430
10	26-Oct-22	1100	88	0.0800	0.0667	0.0893	0.0441
11	31-Oct-22	2400	150	0.0625	0.0667	0.0820	0.0514
12	09-Nov-22	3729	252	0.0676	0.0667	0.0789	0.0544
13	21-Nov-22	1000	70	0.0700	0.0667	0.0904	0.0430
14	28-Nov-22	2600	152	0.0585	0.0667	0.0814	0.0520
Total		29629	1976				

After performing the calculations in the final inspection process using the P-control chart to determine if the data is within the control limits. The DPMO calculation will be carried out. The step to determine the value of DPMO:

- Determine the value of the measured unit (U): The number of products examined in the final inspection process from September to November 2022 was 29629 pcs.
- Determine the value of opportunity (OP): There are three potential failures, as in CTQ.
- Determine the value of defect (D): The number of defects on Stay B Muffler Protector HC21 based on Non-Center Hole Position defects is 1976.
- Calculate Defect per Opportunity (DPO): Defect per unit is calculated by dividing the number of defective products by the total production with a DPO value of 0.02223.
- Calculate Defect Per Million Opportunity (DPMO): Based on the calculation results, it is known that the DPMO value of the Stay B Muffler Protector HC21 product in the final inspection process is 22,230 pcs.

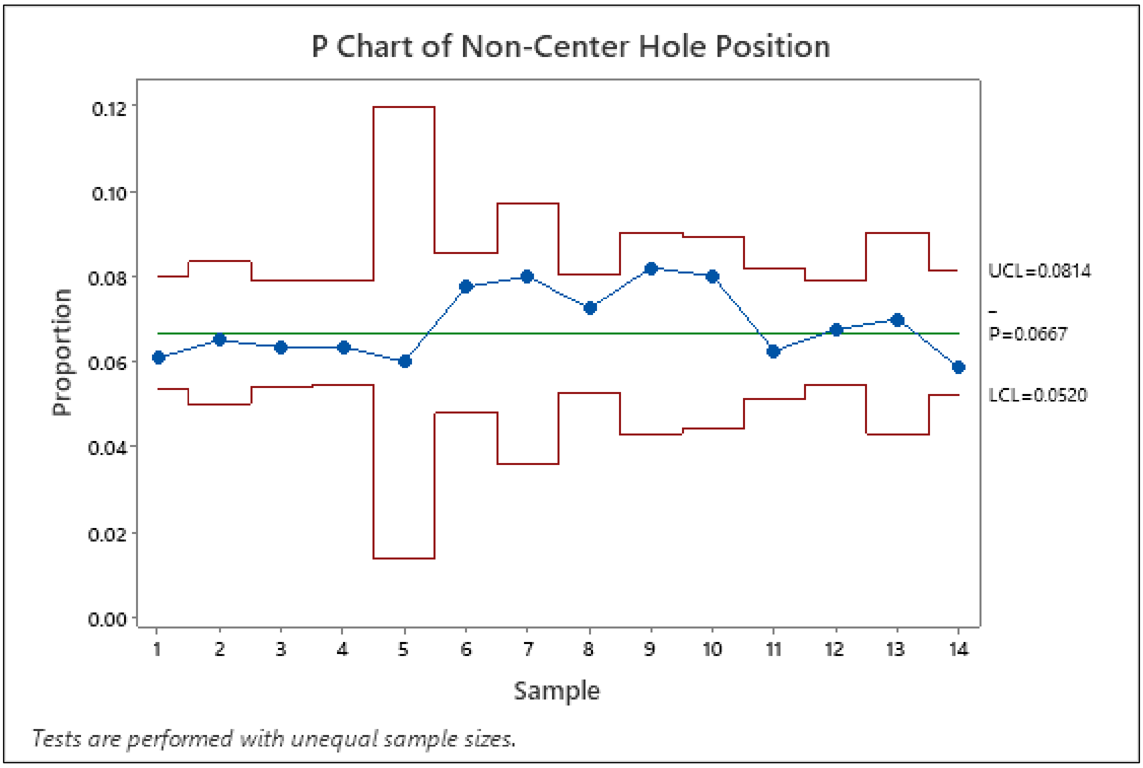

Figure 5 – P-control chart of Non-Center Hole Position

The sigma level is calculated by converting the company's DPMO value to the sigma value table. Based on the sigma table with a DPMO value of 22,230, the company's sigma level is currently at 3.51. This problem makes quality improvement a must to reduce the number of defects and increase sustainability in the Stay B Muffler Protector HC21 production.

4.3 Analyze Stage

The third stage is Analyze, where the causes of the high number of defective products produced in the production process will be identified. At this stage, the tools used are fishbone diagrams and the 5W+1H method. This fishbone diagram (Fig. 6) describes the causes of the problem until the root cause is found due to a defect in the Non-Center Hole Position.

In Fig. 6, the fishbone diagram shows the causal factors as follows:

- Man factor is a factor in the possibility of problems due to labour (production operators):
  a. Operators need to understand the Work Instructions (WI) stages and their impacts because operators are only introduced to the WI stages that must be carried out, but not the impact that will result if there are stages that are not carried out. This problem can be seen from the operator not checking regularly, so the operator does not carry out the process based on WI, where at G point, it is stated that for every output of 100 pcs, a visual check and check jig (a tool used in manufacturing or

woodworking to hold, guide, or support a piece of work while it is being assembled or built to ensure accuracy and consistency) must be carried out by the operator. The previous 20 pcs will be separated and rechecked if one is not included in the jig.

b. Operators become exhausted because parts are made using standard special techniques that require a high concentration level and are only carried out by one operator from the start of production to overtime.

- Machine factor is a factor in the possibility of problems occurring due to the factors of the machine used:

a. During the spot welding process, the tip used on the spot welding machine is not suitable or can be said to be worn out (the diameter has decreased). The tip is worn out because the tip's service life has exceeded the maximum capacity of 18,000 output. The use of worn tips is due to the lack of control over the use of tips that have exceeded their service life.

- Method factor is a factor in the possibility of problems occurring because the method used is not appropriate:

a. The tip storage racks are still mixed up. This problem is because the storage racks do not have an identity that distinguishes between the placement of new and old tips.

b. The operator made a mistake in withdrawing the product when carrying out the spot welding process because the operator did not use standard techniques, so a centre nut tool was made to minimize errors made by the operator's standard techniques.

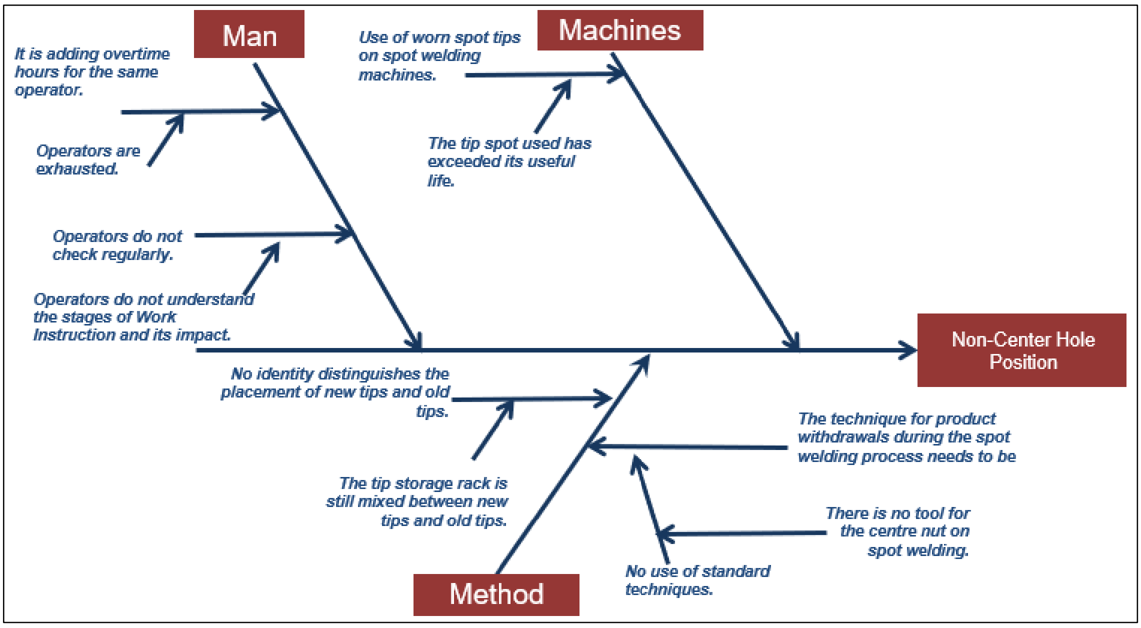

Figure 6 – Fishbone diagram for Hole Position Not Center

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The 5W + 1H analysis is based on the fishbone diagram made previously in Fig. 6. At this stage, every possible factor causing the problem will be described in detail in the form of a 5W + 1H analysis (Tab. 2).

Table 2 – Improvement plan with the 5W+1H analysis

Factor	What	Why	Where	Who	When	How
	Problem	**Reason**	**Location**	**PIC**	**Date to Implement**	**Action**
Man	Operators need to understand WI stages and their impacts.	Operators do not carry out periodic checks, resulting in defective products.	Spot welding area	Leader of Spot welding	1st Week of December 2022	The company carries out Work Instruction (WI) retraining and the impact of each stage if it is not implemented.
	Operators are exhausted.	The same operator does Part Stay B Muffler HC21 until overtime.	Spot welding area	PPIC	1st Week of December 2022	Arrange schedules so operators do not work on the identical product daily.
Machine	The Tip Spot used has exceeded its useful life.	There is no control over the use of tips, so it happens.	Spot welding area	Quality Control	1st Week of December 2022	Make a tip spot control form so that the company can see the amount of output produced from each tip so that it can immediately replace the tip spot if it has exceeded the usage limit.
Method	The tip storage rack is still mixed between new and old tips.	The storage rack has no identity, differentiating the placement between the new and old tips.	Spot welding area	Leader of Spot welding and Quality Control	1st Week of December 2022	It adds identity to the storage rack for placing old tips that are not used.
	There is no tool for the centre nut on spot welding.	The operator made a mistake in withdrawing the product during the spot welding process.	Spot welding area	Quality Control	2nd Week of December 2022	Make tools for centre nuts for spot welding machines.

4.4 Improve Stage

Based on the results of the 5W+1H analysis, an improvement plan has been determined for each of the problems described. The repair plan and implementation of the improvement are as follows:

- Man factor:
  a. Retraining on Work Instruction (WI).

  Retraining will be carried out by the spot welding leader for all spot welding operators. Retraining is carried out to remind again about the standards/ steps that must be followed in the spot welding process following the Work Instruction (WI) and the impact that will occur if WI Steps still need to be carried out (Tab. 3.).

  b. Make Schedule Arrangements.

  Setting the schedule by the PPIC, where the operator is not focused due to fatigue, is caused by the operator doing repetitive work, and for the Stay B Muffler Protector product, there is a unique technique used so that this causes loss of focus, setting a schedule where the operator is not carrying out the spot welding process with the same product from entry to return or when the operator is overtime, this can provide the same workload to all operators so that products with special techniques that have a higher level of difficulty and a higher level of focus are not only one operator per day.

Table 3 – Improvement activity for man factor

Factor	Problem	Improvement	Improvement Status	Documentation of Improvement
Man	The Tip Spot used has exceeded its useful life.	The company carries out Work Instruction (WI) retraining and the impact of each stage if it is not implemented.	Already Implemented	
	Operators are exhausted.	Arrange schedules so operators do not work on the identical product daily.	Already Implemented	--

- Machine factor:
  a. Create a control form for the use of tip spot.

  Making a control form for tip spots serves as a notification to the QC to check the diameter periodically based on the number of products produced (Tab. 4).

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Table 4 – Improvement activity for machine factor

Factor	**Problem**	**Improvement**	**Improvement Status**	**Documentation of Improvement**
Machine	The Tip Spot used has exceeded its useful life.	Make a tip spot control form so that the company can see the amount of output produced from each tip so that it can immediately replace the tip spot if it has exceeded the usage limit.	Already Implemented	

- Method factor:
  a. Added identity for a worn tip spot.

  Automotive SMEs already have a storage rack for tip spot diameter based on the classification of each tip spot, but the storage rack has no place to put tips that are no longer usable (Tab. 5).

  b. Creating the Center Nut Tool.

  Make an Auxiliary Tool for spot welding machines (Fig. 7), which will later function to minimise labour (operator) errors so that the resulting product will have a minimum number of defective products (Sumasto et al., 2023b) in Non-Center Hole Position which results in the product not being included in the jig.

Table 5 – Improvement activity for method factor

Factor	**Problem**	**Improvement**	**Improvement Status**	**Documentation of Improvement**
Method	The tip storage rack is still mixed between new and old tips.	It adds identity to the storage rack for placing old tips that are not used.	Already Implemented	
	There is no tool for the centre nut on spot welding.	Make tools for centre nuts for spot welding machines..	Already Implemented	Fig. 7

Based on the results of the improvement implementation, inspection data for January 2022-March 2023 was obtained, then the results for each percentage of defects (Tab. 6). The results of the improvement have a positive impact on reducing defects not included in the jig from previously 1956 pcs to 120 pcs with a cumulative percentage that was previously 86.5% to 54.5%, as well as a decrease in defects in other types because if there is NG in other types it is already detected in the process before final inspection.

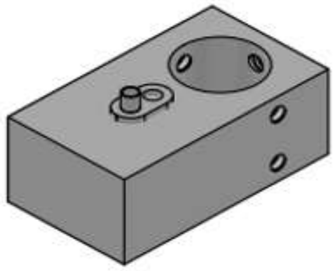
Spot Welding Tool	Before improvement	After improvement
		

Figure 7 – Spot welding tool and tool implementation documentation

Table 6 – Number of defects in Stay B Muffler Protector HC21 after improvement

No	Type of Defects	Number of Defects	Percentage of Defects	Cumulative Percentage of Defects
1	Dent	3	1.4	1.4
2	Bending dented	97	44.1	45.5
3	Non-center hole position	120	54.5	100
Total		220	100	

4.5 Control Stage

The reduction in the number of defects in Stay B Muffler Protector HC21 after repairs is controlled at this stage. The calculation of the sigma level is carried out after the improvement results show a positive impact. The results of the calculation of the sigma level show an increase in the sigma level, which indicates a decrease in the level of process variation and the quality of the Stay B Muffler Protector HC21 product has increased (Tab. 6.). This proves that the improvements made are following the objectives of the research and the methods used can be implemented as a reference for continuous improvement. Tab. 7. shows a comparison of the DPMO and Six Sigma values obtained from the corrective actions that have been taken.

Table 7 – Comparison of the DPMO and Six Sigma values

Value	Before Improvement	After Improvement	Impact
DPMO Value	22,230	2,339	Decreased 19,891
Sigma Level	3.51	4.33	Increased 0.82

5 CONCLUSION

The conclusions that can be put forward in this study include: The dominant factor causing defects is Non-Center Hole Position, which consists of factors man, machines, and methods. Human factors, among others, the operator does not carry out periodic checks, and the operator needs to be more focused. Factors machine include the absence of a control form for the use of tip spots and no placement identity for used tips. The causal factor of the method is that there is no tool to centre the nut on spot welding.

The improvement actions results impact the DPMO value and an increase in the sigma level. DPMO value decreased by 19,891 from 22,230 to 2,339. Meanwhile, the sigma level increased by 0.82 from 3.51 to 4.33. In controlling the sigma level, improvements should be made by creating work instructions for the use of spot welding equipment so that everything can be standardized so that it can be controlled continuously and make continuous improvements. This study shows where the Six Sigma DMAIC approach can drive quality improvement in the Stay B Muffler Protector HC21 production process. This case can help the company's management level to apply the Six Sigma method in solving complex problems in other processes.

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CONFLICTS OF INTEREST

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