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Six Sigma Method for Improving the Quality of a Flat LM Type. An Evidence-Based Case Study of a PT. SPM

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Abstract. PT. SPM is a steel cutting manufacturing company. PT. SPM encountered difficulties during the manufacturing process as a result of the large number of production products classified as defective, particularly flat steel products of the Flat LM type. The company will undoubtedly suffer a loss as a result of the high number of defective products. To reduce the number of defects in manufactured products and to minimize company losses, a study was conducted using the six sigma DMAIC method to ascertain the primary causes of defects and possible improvements. According to the results of the DMAIC analysis, the most prevalent types of defects were dimensional defects that did not match the percentage of 58 percent; non-elbow defects that did not match the percentage of 24 percent; and scratch defects that did not match the percentage of 17 percent. The value of the company's process capability remains less than one (0.776), and the sigma level remains less than six (3.88). There are numerous factors that contribute to defects, including operator negligence, suboptimal machine performance, and an unsupportive work environment. Numerous improvement proposals were made in response to priority issues, including developing SOPs for worker training, developing OPL for the cutting process, and developing machine maintenance checksheets.

INTRODUCTION

The quality of a company's production is critical and should be taken into account by every business. Quality is a dynamic state of affairs in which products, services, people, processes, and the environment meet or exceed expectations[1]. Naturally, the end result of production operations is not always perfect and of high quality. At times, during production, defective products are discovered. The issue of defective items is undoubtedly detrimental to the business because it results in cost overruns. This waste manifests itself in the form of expenditures associated with the use of resources throughout the manufacturing process to manufacture defective items and the subsequent handling of these defective products. As a result, it is required to conduct a quality control process on the product[2]. Quality control can be defined as an efficient system for integrating the development, maintenance, and quality improvement efforts of various groups within an organization in order to maximize the efficiency of marketing, engineering, production, and services while also ensuring complete customer satisfaction[3].

PT. SPM is a company engaged in steel trading and was first established in 2011. In general, the main production of PT. SPM is flat steel and round steel. The production processes carried out are cutting and milling, both of which are carried out to form steel according to the profile desired by the consumer. In the production process, PT. SPM is experiencing problems because of the large number of production results that are classified as defects, especially for flat steel products of the Flat LM type. Flat LM is a type of steel with a flat surface, usually in the form of cubes or blocks and cut according to the size or dimensions desired by the customer. The number of defective products in the Flat LM production certainly causes losses for the company, both in terms of material and time because most types of steel cutting defects cannot be repaired and must be reprocessed from the beginning. Until now, the quality control process that has been carried out by PT. SPM is only a visual check and measurement of product dimensions at the end of the production process.

The six sigma method is one strategy for continuously improving quality. Six sigma is a quality philosophy that strives for a failure rate of no more than 3.4 per million items and is accompanied by an increase in customer base[4]. Six sigma stages are referred to as DMAIC (Define, Measure, Analyze, Improve, and Control). DMAIC is a continuous improvement approach that strives for a six-sigma target value[5]. The six sigma method is projected to boost customer satisfaction and also to reduce losses for PT. SPM, as well as the quantity of defective items generated.

RESEARCH METHODOLOGY

This research was conducted at PT. SPM, a steel cutting production firm. The research process begins with the selection of a study topic, followed by field observations and literature reviews. Following that, problems are identified and formulated. Then, data in the form of production data, defect type data, defect count data, process flow data, and general company data were collected and analyzed utilizing the six sigma DMAIC approach. The define stage involves the identification of common problems that occur at PT. SPM. It is accomplished by the use of a project charter, a SIPOC diagram, and a CTQ. The measure stage involves the Cp and Cpk measurements, control charts, and DPMO and sigma levels calculation. At the analyze stage, the root causes of the problem are identified through the use of Pareto diagrams, fishbone diagrams, and the FMEA method. The improve stage is where proposed modifications are developed based on the recognized sources of the problems. At the control stage, a review of the suggested improvements is conducted to see whether any changes occurred following their implementation. The flowchart in Figure 1 depicted the research methodology.

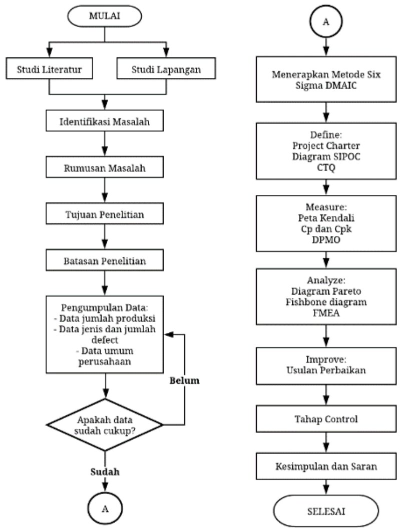

FIGURE 1. Research Methodology Flowchart

RESULTS AND DISCUSSION

Define Stage

The define stage is the first stage in six sigma. It establishes the objectives and action plans that must be implemented, as well as the essential factors that must be addressed by consumers while implementing changes at each stage of the process.

Research Product Selection

The data on which the research is based is data on the type of product with the highest fault rate in comparison to other items. From July 2020 to June 2021, the following table compares the amount of defects for three different types of products manufactured by PT. SPM.

TABLE 1. Comparative Analysis of Product Defects

Types of products	Production Quantity (Units)	Number of Defects (Units)	Percentage
Flat LM	14076	474	3.37%
Flat OC	12511	337	2.69%
Round Steel	10215	257	2.51%

According to Table 1, the product chosen for this research is the Flat LM, which has the highest defect rate of 3.37 percent. Figure 2 illustrates a Flat LM product.

FIGURE 2. Flat LM Product

The following table summarizes the monthly number of Flat LM product defects from July 2020 to June 2021.

TABLE 2. Product Defects of the Flat LM

No	Month	Production Quantity (Units)	Number of Defects (Units)
1	July 2020	1417	44
2	Aug 2020	1019	50
3	Sept 2020	1131	25
4	Oct 2020	1227	64
5	Nov 2020	1675	51
6	Dec 2020	1376	83
7	Jan 2021	1154	21
8	Feb 2021	1123	15
9	March 2021	1012	38
10	Apr 2021	864	19
11	May 2021	1052	46
12	June 2021	1026	18
Total		**14076**	**474**

SIPOC (Supplier-Input-Process-Output-Customers) Diagram

The SIPOC diagram is a straightforward diagram used at the define stage that provides an overview of the process's critical components[6]. Figure 3 shows the SIPOC diagram.

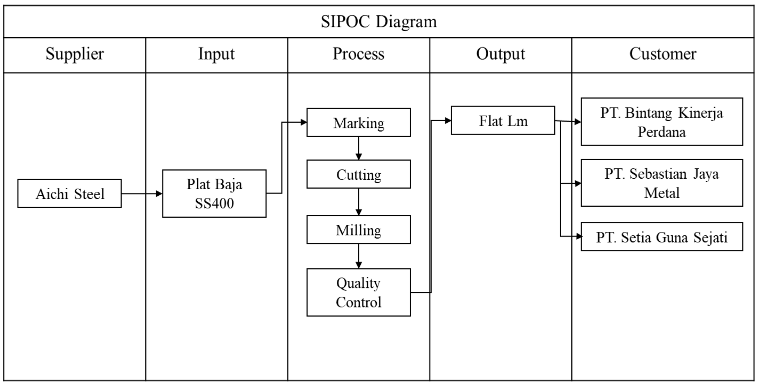

FIGURE 3. SIPOC Diagram

CTQ (Critical to Quality)

The CTQ is the primary characteristic that can be quantified in a process that adheres to norms or restrictions rather than to the specifications required to satisfy consumers[7]. The CTQ is depicted in Figure 4.

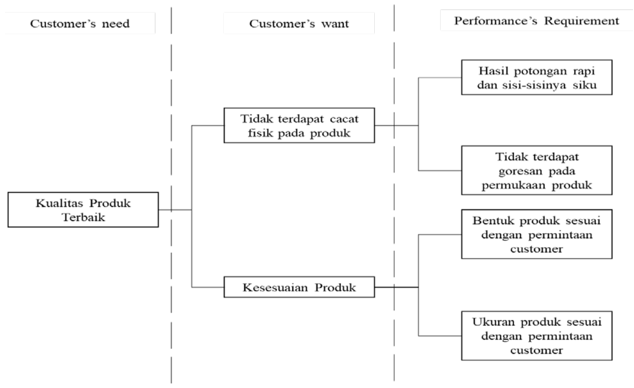

FIGURE 4. CTQ

Measure Stage

Prior to the deployment of quality control activities, measures of the company's condition are made during the measure stage. Pareto diagrams and p-control charts are created at this stage, and the process capability value and sigma level are derived using the DPMO value. The findings of the computation will be utilized as a guide for developing plans based on the gathered data.

P Control Chart

The control chart is one of the instruments used to analyze and comprehend process variables, as well as to monitor their effect on process performance. Additionally, control charts are used to measure the capabilities of a process and to determine whether it is operating within statistical control limitations[3]. The results of the calculation of the P and P-control chart number of Flat LM defects are shown in Table 3 and Figure 5.

TABLE 3. P-Control Chart Calculation Result

Month	Production Quantity (Units)	Number of Defects (Units)	Proportion	CL	LCL	UCL
July 20	1417	44	0.0311	0.0337	0.0193	0.0481
Aug 20	1019	50	0.0491	0.0337	0.0167	0.0506
Sept 20	1131	25	0.0221	0.0337	0.0176	0.0498
Oct 20	1227	64	0.0522	0.0337	0.0182	0.0491
Nov 20	1675	51	0.0304	0.0337	0.0205	0.0469
Dec 20	1376	83	0.0603	0.0337	0.0191	0.0483
Jan 21	1154	21	0.0182	0.0337	0.0177	0.0496
Feb 21	1123	15	0.0134	0.0337	0.0175	0.0498
March 21	1012	38	0.0375	0.0337	0.0167	0.0507
Apr 21	864	19	0.0220	0.0337	0.0153	0.0521
May 21	1052	46	0.0437	0.0337	0.0170	0.0504
June 21	1026	18	0.0175	0.0337	0.0168	0.0506

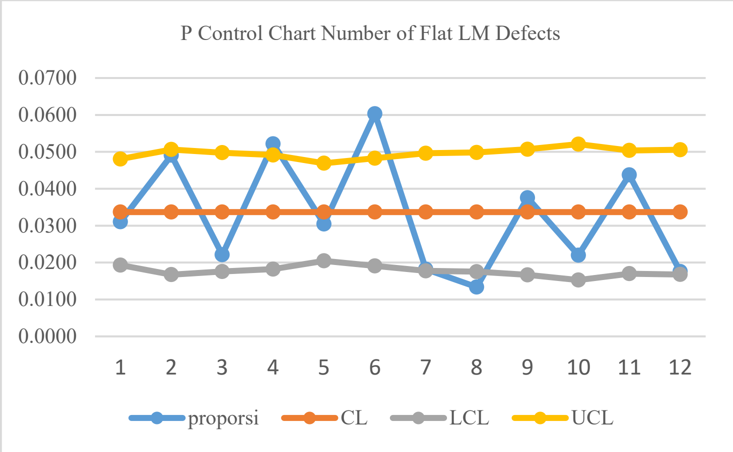

FIGURE 5. P-Control Chart Number of Flat LM Defects

DMPO Calculation and Sigma Level

The DPMO value is used to calculate the sigma level of a business using the formula[8] :

1. Defects per Unit (DPU)

$$\frac{\text{Defect}}{\text{Number of Unit}} \tag{1}$$

$$\frac{474}{14046} = 0{,}033$$

2. Total of Opportunities (TOP)

$$Units\ x\ number\ of\ opportunities\ per\ unit \tag{2}$$

$$14046 \text{ x } 4 = 56184$$

3. Defects per Opportunity (DPO)

$$\frac{\text{Defect}}{\text{Total of Opportunities}} \tag{3}$$

$$\frac{474}{56184} = 0.0084365655$$

4. Defect Per Million Opportunity (DPMO)

$$DPO\ x\ 1000000 \tag{4}$$

$$0.0084365655 \text{ x } 1000000 = 8436.5655$$

5. Sigma Level: The resulting DPMO value is then transformed to a six-sigma conversion table to determine the sigma level. With a DPMO value of 8436.5655, the six sigma conversion table yields a sigma value of 3.88. Table 4 summarizes the DPMO and sigma level calculation results.

TABLE 4. Summary of DPMO Calculation Results and Sigma Level

DPU	0.033
TOP	56184
DPO	0.0084365655
DPMO	8436.5655
Sigma Level	3.88

Calculation of Cp and Cpk [9]

1. Value a = 1 - $\frac{\text{presentasi proporsi defect}}{100 \text{ x } 2}$ (5)

$$= 1 - \frac{3{,}37}{200} = 0.983$$

Knowing the value of a allows for the determination of the value of Z in the normal distribution table. The obtained Z value is 2.12.

2. CP value

$$Cp = \frac{\text{Z value}}{3} \tag{6}$$

$$= \frac{2{,}12}{3} = 0{,}706$$

3. Cpk Value
   To get the Cpk value, the Z value must first be obtained by calculating the A value. Here is the value of A for the purpose of computing CPk.

$$\text{Value a} = 1 - \frac{\text{A value from CP}}{100} \tag{7}$$

$$= 1 - \frac{0{,}983}{100} = 0.990$$

   The z value is 2.33 according to the normal distribution table.

4. Cpk value

$$Cp = \frac{\text{Z value}}{3} \tag{8}$$

$$= \frac{2{,}33}{3} = 0{,}61$$

   The values of Cp and CPk obtained from the calculation are 0.706 and 0.61, respectively. With these findings, it can be concluded that the value of Cp < 1, which represents the process capability of Flat LM production at PT. SPM, is still below par and requires improvement in order to approach the value of 1.

Analyze Stage

At this stage, an analysis is conducted to ascertain the root causes of the observed problems. This process makes use of tools such as fishbone diagrams and FMEA.

Pareto diagram

Using Pareto diagram, it will be possible to identify the specific factors that contribute to problems based on their impact or frequency of occurrence[8]. Flat LM products are considered defective if they do not conform to the product specifications specified by consumers. All products that do not conform to the specifications will be deemed defective and will be withdrawn from distribution to consumers. The types of defects in question are incorrect dimension, non-angle elbows, scratch and porous materials. Table 5 and Figure 6 illustrate the various types of defects and the Pareto diagram.

TABLE 5. Percentage Data of Flat LM Defect

Type of Defect	Number of Defects (Units)	Percentage (%)
Incorrect dimension	273	58%
Non-angle elbow	113	24%
Scratches	80	17%
Porous material	8	2%
Total	**474**	**100%**

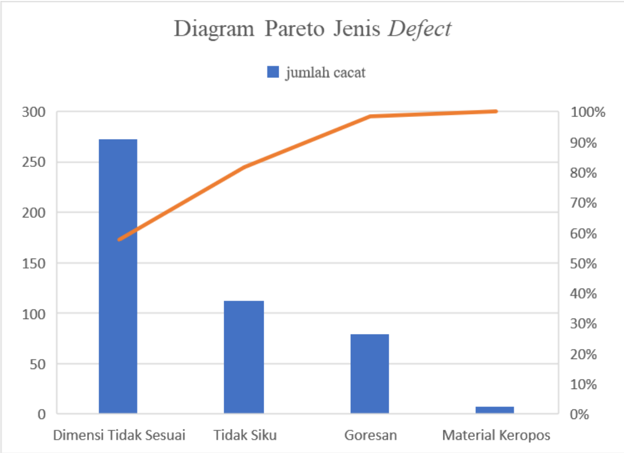

FIGURE 6. Pareto Diagram of the Type of Defect

Fishbone Diagram

A fishbone diagram is one technique for enhancing quality. This diagram is frequently referred to as a cause-and-effect diagram because it depicts the relationship between cause and effect[10]. Figure 7-Figure 9 illustrates the Fishbone diagram of the causes of flat LM product defects.

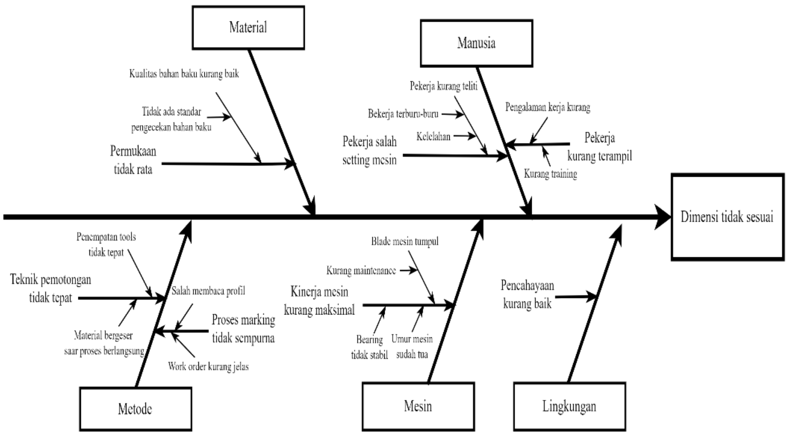

FIGURE 7. Fishbone Diagram of an Incorrect Dimensional Defect

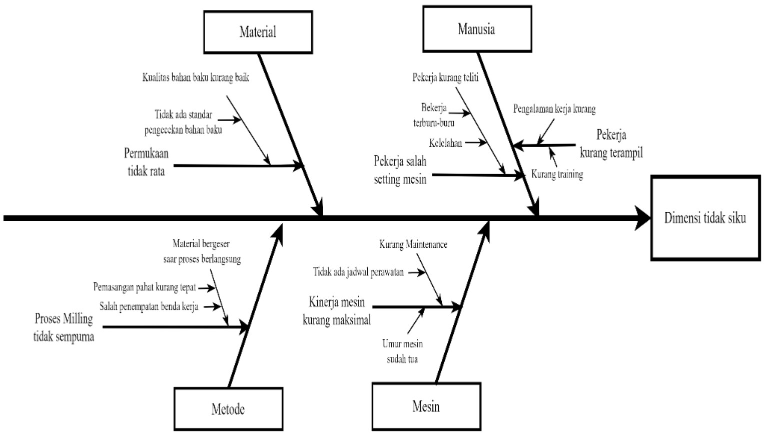

FIGURE 8. Fishbone Diagram of Non-Angle Elbow Defect

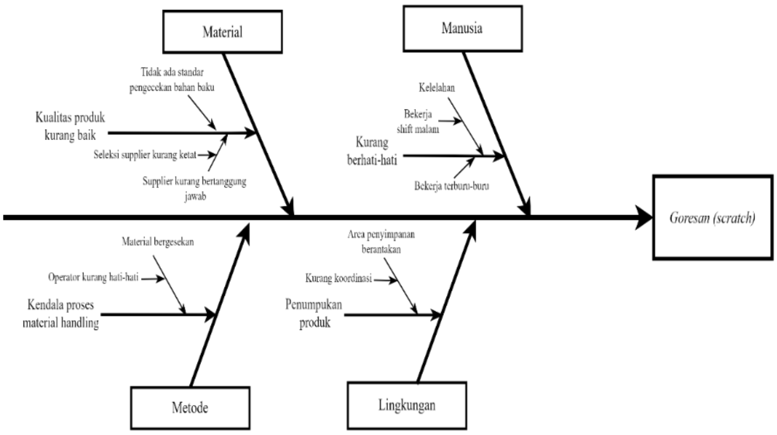

FIGURE 9. Fishbone Diagram of Scratch Defect

The following is an explanation of the causes of *defects* from the fishbone diagram of flat LM product defects:

1. Material Factor
   The uneven surface of the material factor contributes to the occurrence of product defects. If the material's surface is not flat, the measurement and cutting processes will be inaccurate, resulting in defects in the form of incorrect dimensions, so that the product defect does not have an angle. Additionally, poor quality raw materials sourced from unreliable suppliers can result in scratch defects.
2. Machine Factor
   Machine components that have been damaged are a factor in the development of product defects. This machine component can be damaged for a variety of reasons, including a lack of maintenance and the machine's age. Engine spare parts such as bearings and blades that do not function properly as a result of lack of maintenance can cause defects. Additionally, engine age has a negative effect on engine performance.
3. Method Factor
   Inadequate cutting, milling, and material handling processes are undoubtedly contributing to product defects.
4. Human Factor
   Additionally, human factors contribute to product defects. Human error caused by an operator who is not meticulous when setting the machine has a significant impact on the machining results, both during the cutting and milling processes. Additionally, operators with limited work experience risk making errors due to a lack of training and knowledge.
5. Environment Factor
   Environmental factors have an effect on manufacturing defects. Lack of lighting impairs workers' concentration and may result in measurement and cutting errors. Then, because of the limited space for movement, the cramped production area has the potential to make workers uneasy and cause errors.
6. Failure Mode and Effects Analysis (FMEA)
   FMEA is a structured methodology for identifying and analyzing failures that have occurred or may occur, with the goal of preventing these failures from having a detrimental effect on the process's outcome[11] .

TABLE 6. FMEA Analysis of Flat LM Defect

Potential Failure Mode	Effect Of Failure	S	Cause of Failure	O	Current Process Control	D	RPN	Rank	Action Recommended
Incorrect Dimension	Product dimensions do not match the specifications requested by the customer	8	Operator error measuring; machine operation error; less than optimal engine performance	7	Final dimension measurement with ruler/caliper by QC operator	4	224	1	Implementing more detailed and strict SOPs, making one point lessons, machine maintenance inspections

Non-Angle Elbows	Uneven cutting results	8	Operator negligence; uneven material surface	6	Visual check and measurement by operator after cutting process conducted	4	192	2	Implementing more detailed and strict SOPs, making one point lessons, machine maintenance inspections
Scratches	Cannot be forwarded to packing	7	Friction with other materials/objects in storage	4	Visual check performed by the operator on each cutting result	3	84	3	Operators are more careful in material handling and product storage in warehouses
Porous Material	Cannot be cut perfectly	8	The quality of the material from the supplier is not good	3	Use of ultrasonic testing machine	2	48	4	Pay attention to supplier selection

Improve Stage

On the basis of the findings from the analysis of defect causes, several improvement efforts are proposed to resolve the issues, specifically in the form of:

1. Establishing Standard Operating Procedures (SOP) for training employees in order to enhance their skills and knowledge.
2. Creating machine maintenance checklists in order to minimize defects caused by machine damage caused by a lack of maintenance.
3. Creating checksheets for inspecting raw materials before they are sent to suppliers in order to minimize defects caused by low-quality raw materials.
4. Developing a One Point Lesson (OPL) Cutting Process to assist machine operators in comprehending how to operate the process properly and correctly.

Control Stage

The P-control chart is recalculated using the collected data to determine if there is still a proportion of defects that are outside the control limits. The percentage of defects following implementation of the proposed improvements is shown in Table 7.

TABLE 7. Calculation Results Following Implementation of Suggestions

Production Quantity (Units)	Number of Defects (Units)	Proportion	CL	LCL	UCL
50	1	0.02	0.0212	0.0000	0.082345
61	2	0.032787	0.0212	0.0000	0.076559
65	2	0.030769	0.0212	0.0000	0.074829
44	0	0	0.0212	0.0000	0.08638
67	2	0.029851	0.0212	0.0000	0.074023
77	3	0.038961	0.0212	0.0000	0.070474
69	1	0.014493	0.0212	0.0000	0.073252
56	0	0	0.0212	0.0000	0.078977
65	2	0.030769	0.0212	0.0000	0.074829
58	1	0.017241	0.0212	0.0000	0.077972
48	0	0	0.0212	0.0000	0.083605

Figure 10 illustrates the P-control chart following the proposed improvement.

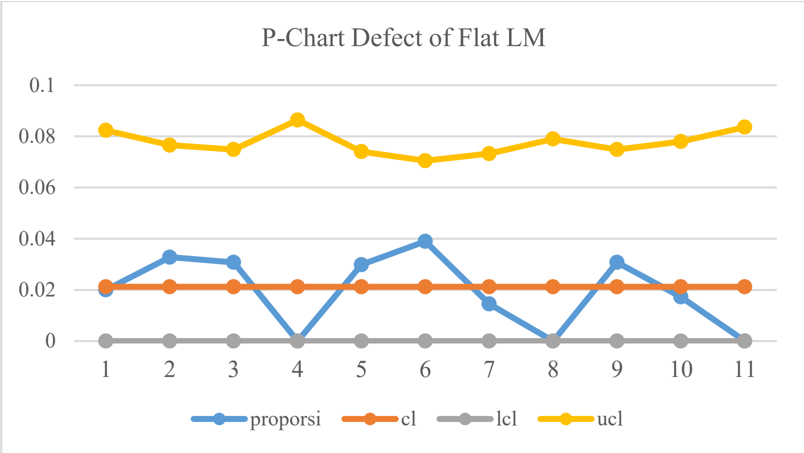

FIGURE 10. The P-Control Chart of Flat LM Defect After Implementing the Proposed Improvement

According to the control chart created following the proposed improvement, the overall proportion of defects is already within the upper control limit (UCL) and lower control limit (LCL). These findings indicate that the proposed or implemented improvements were successful. Following recalculation, the proposed improvements increased the process capability (Cp and Cpk) value closer to 1, decreased the DPMO value to 5303.03, and increased the company's sigma level to 4.05 sigma.

CONCLUSIONS

According to the results of the DMAIC analysis, the type of product chosen as the subject of research is Flat LM, as it has the highest defect rate. The most prevalent types of defects are non-conforming dimensions, which account for 58% of all defects; non-elbow defects, which account for 24% of all defects; and scratch defects, which account for 17% of all defects. With a process capability of 0.61, a DPMO of 8436.5655, and a sigma level of less than six (3.88), it is clear that the company's production process series still requires improvement. The analysis of defect causes reveals a variety of influencing factors, ranging from material factors, machines, methods, and humans to environmental factors. The high RPN value in the FMEA analysis indicates the importance of repairs, with the type of defect with dimensions that are not appropriate or angled having the highest RPN value. Several suggestions for improvement were made based on the highest RPN value, including developing Standard Operating Procedures (SOP) for training employees, creating machine maintenance checksheets, verifying raw material check sheets with suppliers, and developing a One Point Lesson (OPL) cutting process. The proposed improvements increased the process capability (Cp and Cpk) value closer to 1, decreased the DPMO value to 5303.03, and increased the sigma level of the company to 4.05 sigma.

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