

## Analysis of Sickle Product Defects Using Statistical Process Control in a Welding MSME

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### ABSTRACT

Quality control is a critical aspect for the sustainability and competitiveness of Micro, Small, and Medium Enterprises (MSMEs) in the manufacturing sector. A quantitative descriptive-analytical research approach was employed, with data collected through physical inspection and check sheet recording over 20 observation periods. A sample of 20 sickle units was drawn from each observation period, resulting in a total of 400 inspected units. Data analysis was conducted using four Statistical Process Control (SPC) tools : check sheet, Pareto diagram, p-control chart (p-chart), and cause-and-effect diagram (fishbone/Ishikawa). The results revealed that out of 400 inspected units, 32 defective units were identified, resulting in an overall defect rate of 8.00%. Based on the Pareto diagram analysis, the most dominant type of defect was Crack (43.75%), followed by Uneven Thickness (31.25%), and Dull Edge (25.00%). The p-control chart analysis indicated that all data points fell within the statistical control limits (CL = 0.0800; UCL = 0.2620; LCL = 0.0000), suggesting that the production process is in a state of statistical control. Nevertheless, the Defect Per Million Opportunities (DPMO) value of 26,666.7, equivalent to a sigma level of 3.43, indicates that process capability still requires substantial improvement. The fishbone diagram analysis identified defect-causing factors related to Man, Machine, Material, Method, and Environment, with the absence of a written Standard Operating Procedure (SOP) as the most fundamental contributing factor. This study recommends the implementation of a welding SOP, preventive machine maintenance, raw material standardization, operator training, and routine SPC monitoring as structured and continuous quality improvement measures.

## **INTRODUCTION**

Micro, Small, and Medium Enterprises (MSMEs) constitute the backbone of the Indonesian economy, contributing significantly to the national Gross Domestic Product (GDP) and labor absorption (Aprieni et al., 2024). In the manufacturing sector, welding MSMEs play an important role in producing a variety of agricultural tools and household goods, including traditional agricultural implements such as sickles (Sa'diyyah et al., 2020). Nevertheless, MSMEs continue to face significant challenges related to product quality control, production process efficiency, and competitiveness in an increasingly competitive market (Nugraha et al., 2026). Therefore, the implementation of a structured, data-driven quality control system has become an urgent necessity for sustaining and enhancing the competitiveness of MSMEs in the modern industrial era.

Product quality is one of the determining factors in maintaining consumer trust and prevailing in market competition (Sung et al., 2023). In the manufacturing industry, product defects not only result in material losses through waste of raw materials and labor, but also negatively affect the manufacturer's reputation and customer satisfaction (Munteanu et al., 2014). As a traditional agricultural tool commonly used by farmers in Indonesia, particularly on Lombok Island, sickle products are required to meet specific quality standards related to sharpness, material hardness, dimensional accuracy, and resistance to workloads. Defects in sickle products, such as cracks at welding joints, dimensional non-conformance, uneven surface finish, or non-uniform hardness distribution, may potentially cause occupational accidents and reduce agricultural productivity. Accordingly, efforts to identify, measure, and control product defects in sickle products are of critical importance for welding MSME workshops in order to produce products that are consistent and of high quality.

Statistical Process Control (SPC) is one of the most widely applied quality control approaches in the manufacturing industry worldwide (Vanli & Castillo, 2021 ; Soeryono et al., 2025). This method employs statistical techniques, such as control charts, Pareto diagrams, cause-and-effect diagrams (fishbone/Ishikawa), histograms, and check sheets, to systematically monitor, analyze, and control variation in production processes (Montgomery, 2020). By identifying both common cause and special cause variation, SPC enables manufacturers to take appropriate corrective actions before defects escalate into more serious problems. Consistent implementation of SPC has been demonstrated to reduce product defect rates, lower production costs, and improve overall process efficiency (Heizer & Render, 2020).

Based on the foregoing background, this study aims to analyze the types of defects occurring in sickle products manufactured by a Welding MSME Workshop in Mataram City, West Nusa Tenggara, using the Statistical Process Control (SPC) approach. Specifically, this study will identify the dominant types of defects through check sheets and Pareto diagrams, determine process control limits using attribute control charts, and analyze the causal factors of defects using a cause-and-effect diagram. The findings of this study are expected to provide a practical contribution in the form of production process improvement recommendations that can be implemented by welding MSME workshops in their efforts to continuously enhance sickle product quality. Furthermore, this study is also expected to enrich the academic body of knowledge in the field of quality management, particularly regarding the application of SPC in micro and small-scale manufacturing industries in Indonesia.

## **METHODS**

### **Research Type and Approach**

This study employed a quantitative approach with a descriptive-analytical research design. The quantitative approach was selected because this study focuses on the measurement and analysis of numerical data pertaining to the frequency and proportion of sickle product defects at the Welding MSME Workshop in Mataram City. The primary method utilized was Statistical Process Control (SPC), a statistical-based quality control method designed to monitor and control variation in production processes (Montgomery, 2020). Through this approach, the study sought to identify the dominant types of defects, determine whether the production process was in a state of statistical control, and analyze the causal factors contributing to product defects.

### **Research Location and Period**

The study was conducted at a Welding MSME Workshop located in Mataram City, West Nusa Tenggara Province. The research site was selected purposively, based on the consideration that the workshop is one of the active sickle product manufacturers serving the agricultural needs of farmers in the Lombok region, yet has not implemented a standardized quality control system. Observational data collection was carried out over a period encompassing 20 active production days, taking into account raw material availability, daily production capacity, and representative workshop operational conditions.

### **Research Object and Population**

The research object consisted of sickle products manufactured by the Welding MSME Workshop in Mataram City. The study population encompassed all sickle product units produced during the observation period. A systematic sampling technique was employed, whereby 20 sickle product units were drawn as inspection samples on each observation day. The determination of a daily sample size of 20 units was based on the consideration of the workshop's daily production capacity and the minimum sample size requirement for a statistically valid attribute control chart, namely  $n \geq 20$  (Besterfield, 2012). Consequently, the total number of units inspected throughout this study amounted to 400 sickle product units (20 days  $\times$  20 units/day).

### **Variables and Operational Definitions**

The primary variable in this study was sickle product defects, defined as non-conformance of the product with the established quality standards. Based on preliminary observations and interviews with production operators, three types of defects were identified as the focus of observation: (1) Dull Edge, a condition in which the sickle blade fails to achieve an adequate level of sharpness for agricultural use, attributable to suboptimal forging and grinding processes; (2) Uneven Thickness, a condition in which the thickness distribution of the sickle body is inconsistent, potentially caused by non-uniform rolling or forging processes; and (3) Crack, the presence of fractures or gaps in the sickle body or welding joint area, constituting the most hazardous type of defect as it may cause structural failure during field use.

### **Data Collection Technique**

Data in this study were collected through direct observation and physical product inspection techniques. Each sample unit was examined visually and through simple testing conducted by the researcher in collaboration with experienced workshop operators. Inspection results were recorded on a check sheet specifically designed to systematically document the three aforementioned types of defects. The check sheet constitutes the most fundamental data collection instrument in SPC and serves as the primary data source for subsequent analysis (Rahmawati et al., 2025).

### **Data Analysis Technique**

Data analysis in this study employed statistical tools forming part of the Statistical Process Control (SPC) framework, comprising the following:

#### **Pareto Diagram.**

The Pareto diagram was used to identify and prioritize the most dominant types of defects based on their frequency of occurrence (Hidayat et al., 2026). The Pareto principle states that approximately 80% of quality problems are caused by 20% of defect types (Kwilinski & Kardas, 2024).

#### **P-Control Chart (p-Chart).**

The p-control chart was used to monitor the proportion of defects in each sample against the established statistical control limits (Wotango et al., 2025). The p-control chart was selected because the defect data are of an attribute nature (yes/no) and the sample size employed is constant ( $n = 20$  units per period). The formulas used to calculate the Center Line (CL), Upper Control Limit (UCL), and Lower Control Limit (LCL) are as follows (Montgomery, 2020):

$$\bar{p} = \Sigma np / \Sigma n \dots\dots\dots(1)$$

$$UCL = \bar{p} + 3\sqrt{(\bar{p}(1-\bar{p})/n)} \dots\dots(2)$$

$$LCL = \bar{p} - 3\sqrt{(\bar{p}(1-\bar{p})/n)} \dots\dots(3)$$

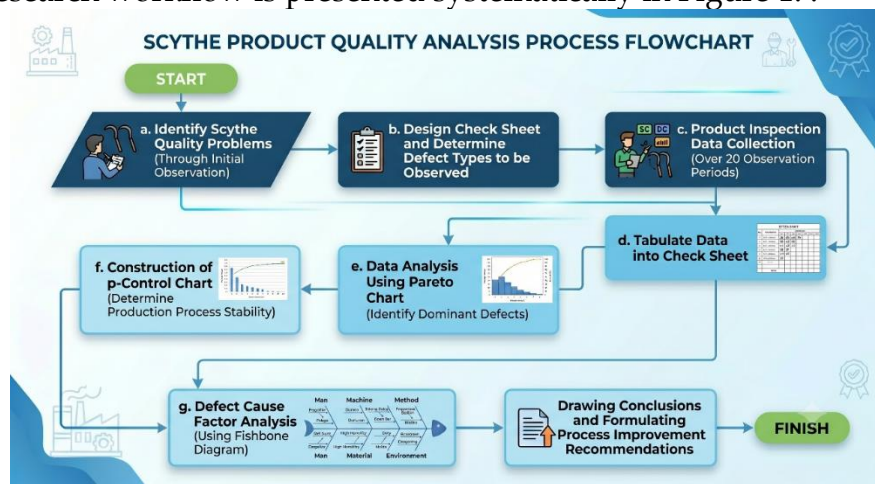
$\bar{p}$  is the average defect proportion,  $np$  is the number of defective units in each sample,  $n$  is the sample size,  $UCL$  is the upper control limit, and  $LCL$  is the lower control limit. A negative  $LCL$  value is rounded to 0.

**Cause and Effect Diagram (Fishbone/Ishikawa Diagram).**

The cause-and-effect diagram was used to systematically analyze and map the defect-causing factors based on five primary categories: Man, Machine, Material, Method, and Environment (Kumah et al., 2024 ; Ciecńska, 2024). Root cause identification was conducted through a combination of field observation, in-depth interviews with operators and the workshop owner, and a review of the relevant literature on welding and metal forging processes.

**Research Workflow**

The research workflow is presented systematically in Figure 1. :



**Figure 1. Research Flowchart**

All stages of this analysis are guided by the Plan-Do-Check-Act (PDCA) quality control cycle, which serves as the philosophical foundation of the SPC method.

**RESULTS**

**Data Collection Results (Check Sheet)**

Data collection was carried out over 20 observation periods, with 20 sickle product units inspected per period, resulting in a total of 400 units examined. Each unit was inspected for three types of defects as previously defined, namely: Dull Edge, Uneven Thickness, and Crack. The results recorded on the check sheet are presented in full in Table 1 below.

**Table 1. Recapitulation of Check Sheet Data on Sickle Product Defects**

No	Observation Sample	Dull Edge	Uneven Thickness	Crack	Total Defects
1	20	2	1	0	3
2	20	0	0	2	2
3	20	0	0	0	0
4	20	0	0	1	1

5	20	0	0	0	0
6	20	1	1	1	3
7	20	0	1	1	2
8	20	0	0	0	0
9	20	0	1	1	2
10	20	1	1	0	2
11	20	2	1	1	4
12	20	0	1	1	2
13	20	0	0	1	1
14	20	0	1	2	3
15	20	1	0	0	1
16	20	0	1	0	1
17	20	1	0	1	2
18	20	0	1	1	2
19	20	0	0	0	0
20	20	0	0	1	1
Total	400	8	10	14	32

Based on Table 1, out of the 400 sickle product units inspected over 20 observation periods, 32 units were found to contain at least one type of defect, yielding an overall defect rate of 8.00% (32/400). The defect distribution reveals that the Crack defect type was the most frequently occurring, with 14 occurrences, followed by Uneven Thickness with 10 occurrences, and Dull Edge with 8 occurrences. It is further observed from the table that four observation periods (periods 3, 5, 8, and 19) recorded no defective products whatsoever, whereas period 11 registered the highest number of defects, with 4 units in a single observation period.

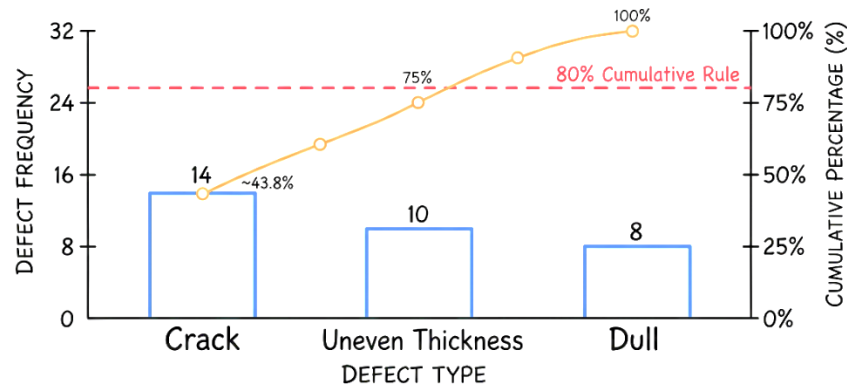
#### Pareto Diagram Analysis

The Pareto diagram was employed to identify and prioritize defect types based on their frequency of occurrence. The Pareto principle (80/20) states that the majority of quality problems (80%) are generally attributable to a small proportion of defect types (20%) (Juran, 1974). A summary of the data for the Pareto diagram is presented in Table 2 below.

**Table 2. Distribution of Sickle Product Defects for the Pareto Diagram**

Defect Type	Total Defects	Percentage (%)	Cumulative (%)	Rank
Crack	14	43.75	43.75	1
Uneven Thickness	10	31.25	75.00	2
Dull Edge	8	25.00	100.00	3
Total	32	100,00	-	-

Based on Table 2 and Figure 2, the Pareto analysis indicates that the Crack defect is the most dominant type, accounting for 14 units (43.75%), followed by Uneven Thickness with 10 units (31.25%), and Dull Edge with 8 units (25.00%). When the two most prevalent defect types, namely Crack and Uneven Thickness, are combined, they collectively account for 24 units, or 75.00% of the total defects identified.



**Figure 2. Pareto Chart of Defect**

These findings are consistent with the Pareto principle, wherein two out of three defect types (67%) are responsible for 75% of all defects. Therefore, quality improvement efforts should be prioritized toward addressing Crack and Uneven Thickness defects in order to achieve the most significant reduction in overall defect rates. The Crack defect, which dominates the findings of this study, is theoretically closely related to the quality of the welding process, encompassing parameters such as welding current, welding speed, preheat temperature, and the composition of the electrode material used. According to Lincoln Electric (2020), cracks in welding joints are generally caused by a combination of excessive residual stress, high hydrogen content in the weld metal, and an excessively rapid cooling rate. Such conditions are highly probable in welding MSME workshops that have not yet implemented standardized welding procedures.

### *p*-Control Chart Analysis (*p*-Chart)

#### **Control Limit Calculation**

The *p*-control chart was used to monitor the proportion of defective units (*p<sub>i</sub>*) in each observation period against the established statistical control limits. With a constant sample size of  $n = 20$  units per period and a total number of defective units  $\sum np = 32$  out of a total inspection of  $\sum n = 400$ , the average defect proportion ( $\bar{p}$ ) is calculated as follows:

$$\bar{p} = \sum np / \sum n = 32 / 400 = 0.0800$$

The Upper Control Limit (UCL) and Lower Control Limit (LCL) are calculated using the *p*-control chart formula as follows:

$$UCL = \bar{p} + 3\sqrt{\bar{p}(1-\bar{p})/n} = 0.0800 + 3\sqrt{(0.0800 \times 0.9200 / 20)}$$

$$UCL = 0.0800 + 3 \times 0.0606 = 0.0800 + 0.1820 = 0.2620$$

$$LCL = \bar{p} - 3\sqrt{\bar{p}(1-\bar{p})/n} = 0.0800 - 0.1820 = -0.1020 \approx 0.0000$$

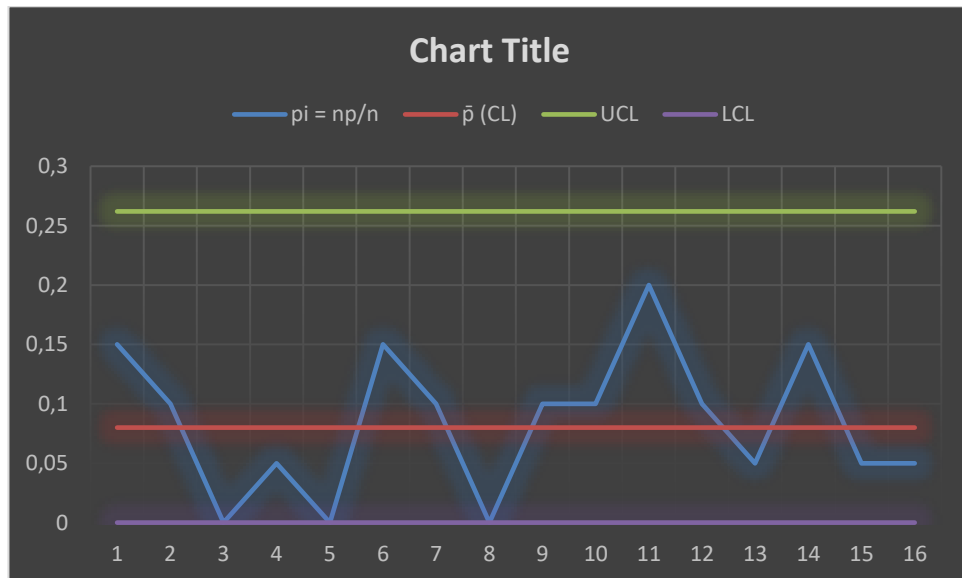
The negative LCL value (-0.1020) is rounded to 0, since a defect proportion cannot logically be negative (Montgomery, 2020). Accordingly, the three control lines are established as follows: Center Line (CL) = 0.0800, Upper Control Limit (UCL) = 0.2620, and Lower Control Limit (LCL) = 0.0000.

#### 3.1. *p*-Control Chart Data and Evaluation

The defect proportion values (*p<sub>i</sub>*) for each observation period along with their corresponding control lines are presented in Table 3 below.

**Table 3. p-Control Chart Data for Sickle Product Defects**

No	n	np	$p_i = \frac{np}{n}$	$\bar{p}$ (CL)	UCL	LCL
1	20	3	0.1500	0.0800	0.2620	0.0000
2	20	2	0.1000	0.0800	0.2620	0.0000
3	20	0	0.0000	0.0800	0.2620	0.0000
4	20	1	0.0500	0.0800	0.2620	0.0000
5	20	0	0.0000	0.0800	0.2620	0.0000
6	20	3	0.1500	0.0800	0.2620	0.0000
7	20	2	0.1000	0.0800	0.2620	0.0000
8	20	0	0.0000	0.0800	0.2620	0.0000
9	20	2	0.1000	0.0800	0.2620	0.0000
10	20	2	0.1000	0.0800	0.2620	0.0000
11	20	4	0.2000	0.0800	0.2620	0.0000
12	20	2	0.1000	0.0800	0.2620	0.0000
13	20	1	0.0500	0.0800	0.2620	0.0000
14	20	3	0.1500	0.0800	0.2620	0.0000
15	20	1	0.0500	0.0800	0.2620	0.0000
16	20	1	0.0500	0.0800	0.2620	0.0000
17	20	2	0.1000	0.0800	0.2620	0.0000
18	20	2	0.1000	0.0800	0.2620	0.0000
19	20	0	0.0000	0.0800	0.2620	0.0000
20	20	1	0.0500	0.0800	0.2620	0.0000
Total	400	32	-	-	-	-



**Figure 3. p-Control Chart for Sickle Product Defects**

Based on Table 3 and Figure 3, all defect proportion values ( $p_i$ ) across the 20 observation periods fell within the control limits, specifically between  $LCL = 0.0000$  and  $UCL = 0.2620$ . The highest  $p_i$  value occurred in period 11, reaching 0.2000 (4 defective units out of 20 sampled units), while the lowest  $p_i$  value of 0.0000 was recorded in periods 3, 5, 8, and 19. No data point was found to lie outside the control limits (out of control).

#### **Interpretation of p-Control Chart Results**

The fact that all data points remained within the statistical control limits indicates that the sickle production process at the Welding MSME Workshop in Mataram City is in a state of statistical control. This condition signifies that the defect variation observed during the observation period can be explained by common cause variation, that is, natural variation inherent to the process, and is not attributable to extraordinary special cause variation (Montgomery, 2020).

Although the process is deemed to be in statistical control, it is important to emphasize that this condition does not imply that the process has attained an optimal quality standard. The average defect rate of 8.00% ( $\bar{p} = 0.0800$ ) remains relatively high by manufacturing industry standards. For comparative reference, competitive industry standards generally target defect rates below 1%, or even approaching the Six Sigma standard of 3.4 defects per million opportunities (DPMO). Based on the DPMO estimate calculated from the data of this study, a DPMO value of 26,666.7 was obtained, equivalent to a sigma level of approximately  $3.43\sigma$ . This value indicates that the sickle production process at the workshop still requires substantial improvement efforts to achieve a competitive quality level.

Furthermore, the distribution pattern of data points on the control chart reveals a tendency for certain periods to record  $p_i = 0.0000$ , interspersed with defect spikes in specific periods (such as periods 1, 6, 11, and 14). Such a fluctuation pattern suggests the possible presence of periodic factors influencing production quality, including variations in operator physical condition, the

arrival of new materials from different suppliers, or variations in the condition of production equipment at certain times.

1. Cause-and-Effect Diagram Analysis (Fishbone/Ishikawa)

To identify the root causes of defects in greater depth, an analysis was conducted using the cause-and-effect diagram (fishbone diagram) developed by Kaoru Ishikawa. This analysis was based on the results of field observation, interviews with operators and the workshop owner, as well as a comprehensive review of the production process. The defect-causing factors were categorized into five primary dimensions, as presented in Figure 4.

Based on the analytical results presented in Figure 4, it can be identified that sickle product defects at the Welding MSME Workshop in Mataram City originate from a combination of interrelated factors. The Man factor exerts the most direct influence, wherein operator fatigue due to extended working hours and the absence of standardized technical competency contribute significantly to the occurrence of all defect types.

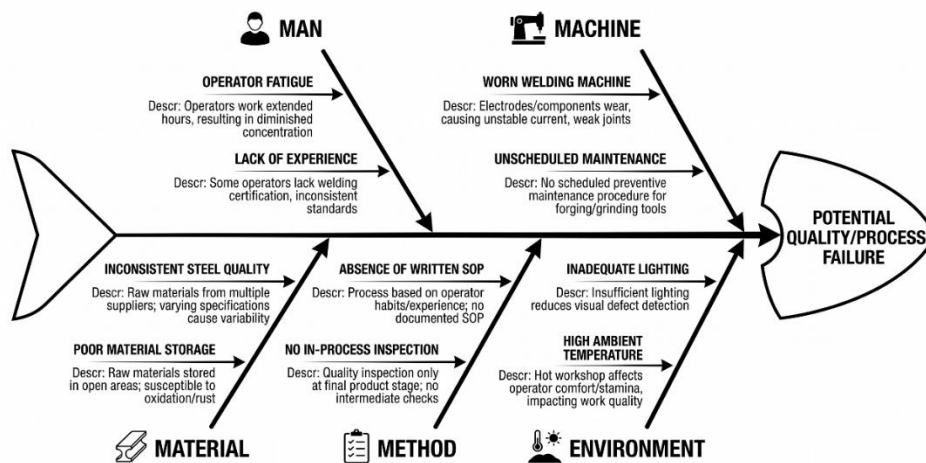


Figure 4. Analysis of Defect-Causing Factors (Fishbone/Ishikawa Diagram)

The Machine factor, particularly the instability of welding current attributable to worn electrodes and welding machine components, constitutes the primary cause of the Crack defect. A welding process that fails to achieve complete fusion between the base metal and filler metal creates weak points at the welding joint that are susceptible to cracking, especially when the product is subjected to impact loads during field use. The Material factor is associated with inconsistencies in the quality of steel raw materials received from multiple suppliers. Variations in carbon content and steel purity directly affect the characteristics of the welding and forging processes, resulting in products with non-uniform thickness and hardness distribution.

The Method factor is the most fundamental, as the absence of a written Standard Operating Procedure (SOP) renders the production process heavily dependent on the individual habits and intuition of each operator. This condition generates high variability both between operators and across production periods. The absence of in-process inspection also means that defects are only detected at the final production stage, thereby precluding early and timely corrective action.

### Improvement Recommendations

Based on the comprehensive analytical results encompassing the Pareto diagram, p-control chart, and fishbone diagram, a number of structured process improvement recommendations have been formulated, as presented in Table 5.

The implementation of the recommendations outlined in Table 5 should be carried out in a phased manner, prioritizing the resolution of the Crack defect as the primary concern, given that this defect type exhibits the highest frequency (43.75%) and simultaneously poses safety risks to product users in the field. The first recommended phase is the development of a written welding SOP that encompasses welding parameter specifications (current, voltage, speed), pre-welding procedures (material cleaning, preheat), and visual inspection standards at each production stage. The second phase involves enhancing operator competency through structured technical welding training, ideally progressing toward nationally recognized welding certification. The third phase entails the implementation of a continuous quality monitoring system using the p-control chart, to be routinely conducted by workshop management as a daily quality control tool.

**Table 5. Process Improvement Recommendations**

No	Defect Type	Root Cause	Improvement Recommendation
1	Crack	Worn machine, inconsistent material, absence of SOP	Schedule regular machine maintenance, standardize raw materials from a single supplier, develop a written welding SOP
2	Uneven Thickness	Non-standardized forging method, worn equipment	Develop dimensional references (jig/fixture) for forging, conduct periodic calibration of measuring instruments
3	Dull Edge	Inconsistent grinding process, operator fatigue	Establish grinding angle and duration standards, implement shift rotation and structured rest periods for operators
4	General (System)	Absence of a formal quality control system	Implement SPC routinely, train operators on fundamental quality concepts, and introduce in-process inspection

Overall, the application of the Statistical Process Control method at the Welding MSME Workshop in Mataram City serves not only as a quality problem detection tool but also as a foundation for building a quality culture oriented toward continuous improvement. With reference to the Plan-Do-Check-Act (PDCA) cycle introduced by Deming (1986), the findings of this study can serve as a baseline for subsequent improvement cycles, wherein the target of a gradual reduction in defect rates from 8.00% to below 5% in the first cycle, and subsequently to below 1% in the long term, represents a realistic and measurable objective for this MSME to achieve.

## **CONCLUSIONS**

This study successfully analyzed sickle product defects at the Welding MSME Workshop in Mataram City using the Statistical Process Control (SPC) method. Out of 400 product units inspected over 20 observation periods, 32 defective product units were identified, yielding a defect rate of 8.00%. Based on the Pareto diagram analysis, the Crack defect was found to be the most dominant type (43.75%), followed by Uneven Thickness (31.25%) and Dull Edge (25.00%), with the two most prevalent defect types cumulatively accounting for 75.00% of total defects.

The p-control chart analysis revealed that all data points fell within the statistical control limits (CL = 0.0800; UCL = 0.2620; LCL = 0.0000), indicating that the production process is in a state of statistical control. Nevertheless, the DPMO value of 26,666.7, equivalent to a sigma level of 3.43 $\sigma$ , indicates that process capability still requires substantial improvement to meet competitive industry standards.

The fishbone diagram analysis identified the absence of a written Standard Operating Procedure (SOP) as the most fundamental contributing factor, compounded by operator fatigue, welding machine wear, raw material inconsistency, and inadequate working environment conditions. Therefore, the development of a welding SOP, the implementation of preventive machine maintenance, raw material standardization, and routine SPC implementation represent the most urgent improvement measures to be undertaken in order to sustainably reduce product defect rates.

## **RECOMMENDATIONS**

Based on the findings of this study, the welding MSME is recommended to prioritize improvements in welding procedures and operator competency to reduce the occurrence of crack defects. The development of a written Standard Operating Procedure (SOP), implementation of preventive machine maintenance, and standardization of raw material suppliers are strongly recommended to minimize process variation.

Furthermore, routine implementation of Statistical Process Control (SPC), particularly through the use of p-control charts and periodic quality inspections, is recommended to support continuous quality improvement. Future studies are also encouraged to integrate laboratory-based material testing and advanced quality control methods such as Failure Mode and Effects Analysis (FMEA) or Six Sigma to obtain more comprehensive process improvement strategies.

## FURTHER STUDY

This study has several limitations that warrant acknowledgment. First, observations were conducted over only 20 production periods with a daily sample size of 20 units; therefore, any generalization of the findings should be made with due caution. Increasing the number of observation periods and sample sizes in future studies will yield more accurate and representative process parameter estimates. Second, the analysis of defect-causing factors in the fishbone diagram remains qualitative in nature, based on observation and interviews; accordingly, future research that integrates laboratory-based material testing will provide stronger empirical confirmation of the identified causal factors.

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