Quality Control of Steel Deformed Bar Product using Statistical Quality Control (SQC) and Failure Mode and Effect Analysis (FMEA)

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Abstract. The Percentage of steel deformed bar product defect in an Indonesian factory was 0.064% by 2019, where the defect percentage exceeded a limit target set by the company, which is 0.050%. This research used a Statistical Quality Control (SQC) method by applying the Seven Tools to identify the problems that caused defects in the product. The author also applied Failure Mode and Effect Analysis (FMEA) method into the production process to generate solutions for the cause of dominant defect factors. According to the calculated RPN value, the cross defect was caused the most by uncentered between top roll and bottom roll. For scratch defect, the main factor carried by Spindle Carrier that is vibrating during the rolling process. The line defect caused by a worn caliber. By implementing the recommended solution, the percentage of product defects decreased from 0.064% to 0.0075% during March to June 2020.

1. Introduction
Along with the increasing competition in an industrial product, the quality of a product is one of the considered factors by a customer before buying, so focusing on the product quality becomes more beneficial to win in a business competition. By increasing the quality of a product, the income will increase, and the needed cost for a production process can be reduced [1]. As one of the upstream steel products, the steel deformed bar is widely used in manufacturing needs [2]. Steel deformed bar is set its standard quality requirements on SNI 2052:2017 [3] for the aspect of mechanical and physical properties. To meet the quality standard, there are some factors become the cause of product defect. Therefore, a study is needed to find that cause factors as well as the solution for the problems, so that the finish product can be more quality and fewer of defects [4].

This research applies the Statistical Quality Control (SQC) and Failure Mode and Effect Analysis (FMEA) method for identifying the defect cause in steel deformed bar products. The utilization of SQC and FMEA often used by other studies, such as Houchi [5] that used SQC to determine the best method to estimate the direction of movement of the wind. Another researcher, such as Rida [6], mixed SQC and FMEA to find product defects. In the study which is done by Reynaldi [7], implementing the SQC method on steel deformed bar was successfully offering the solution for volume and length defect for the finish product. Nowadays, the study that combines both SQC and FMEA method for identifying the defect on steel deformed bar is rarely done and need specific research to discover more about the factor that caused the defect on the product and to see the result from implemented solution [8].

2. Method and materials
Managing the quality, there are many approaches offered, such as improving the system [9], implementing steps quality improvement, or approaching the tools that can help for
controlling the quality [10]. Quality control is a technical and management activity that measures quality characteristic of a product or a service, then compare the measured result with product specification and taking the improvement action appropriately if there is a difference among the product standard [11]. Statistical Quality Control (SQC) offers the tools for solving the problem such as process stability, identify opportunities to improve, and decreasing the variability [12]. Control in SQC uses Seven Tools to improve the process, and finishing product defects can be minimalized [13]. Another method is Failure Mode and Effect Analysis (FMEA) that able to outlines the problems of the dominant process so that the improvement can be applied. By combining the quality control through SQC and detection of process failure with FMEA, the finishing product will get more improve [14].

There are several types of defects in this company product, where the average percentage of product defect exceeds the limit target set by the company, which is 0.050%. The defect such as cross, scratch surface, and appearance a line on the physical product. The data of defect on product obtained during production result from January to November 2019. Data were processed using a check sheet to sort out the number sequence of defects, and then the data was identified by the stratification method for the number of defects per type of product defect. The result from stratification then inputted to the histogram chart, Pareto diagram, scatter diagram so that dominant and necessary defects can appear. Then, each appeared defect, calculated its coefficient of correlation to find out if there is a relation between the defects and the number of production. Then, the fishbone diagram used to analyze the factor that causes the defects, and also make a solution upon the cause. The author describes the problem of defects through data analysis and interviews with related departments.

FMEA method applied in the production process that started by doing some interviews with the production supervisor with focusing on the effect of the defect and determining the detection method. Then, the author sets the value level of severity (S), occurrence (O), detection (D), and the RPN value for each defect. Corrective action for each defect was prioritized from the highest RPN value to RPN value at 100 points. After the solution was determined, it applied to the production process started from March to June 2020, so that the impact of using the solution through SQC and FMEA can be obtained.

3. Results and discussion

The production process of the steel deformed bar is derived into various steps. It started with the raw material such as a billet, reheating furnace step, rolling, and packaging. In this research, the rolling section becomes a research focus. The data of product defects by 2019 are shown as below:

| No | Month 2019 | Production (kg) | Defect (kg) | % of defect |
|----|------------|----------------|-------------|-------------|
| 1  | January    | 36,201,132     | 34,805      | 0.096       |
| 2  | February   | 31,441,279     | 16,948      | 0.054       |
| 3  | March      | 29,052,615     | 18,298      | 0.063       |
| 4  | April      | 37,159,197     | 28,150      | 0.076       |
| 5  | May        | 38,218,605     | 32,192      | 0.084       |
| 6  | June       | 35,167,828     | 14,682      | 0.042       |
| 7  | July       | 39,010,231     | 25,370      | 0.065       |
| 8  | August     | 40,240,470     | 31,452      | 0.078       |
| 9  | September  | 40,731,536     | 10,602      | 0.026       |
| 10 | October    | 36,469,482     | 27,330      | 0.075       |
| 11 | November   | 39,867,335     | 19,080      | 0.048       |
| **Total** | 403,559,710 | 258,909      | 0.064%      |
From the table 1 shows that the percentage of defects in the production process of steel deformed bar is still high at 0.064%, while the percentage defect allowed by the company is maximum at 0.050% of total production. This study aims to find solutions on defect problems so that the percentage of product defects is below the threshold taken down by the company.

3.1. Defect Identification

Product defect data have checked using a check sheet. The following table is data on the number and types of defects of steel deformed bar products in this study:

| No | Month (2019) | Type of Defect (Kg) |
|----|--------------|---------------------|
|    |              | Scratch  | Line    | Cross  | Thin ribs |
| 1  | January      | 9,213    | 8,190   | 12,286 | 5,116     |
| 2  | February     | 4,583    | 3,477   | 6,716  | 2,172     |
| 3  | March        | 4,843    | 4,306   | 6,459  | 2,690     |
| 4  | April        | 7,451    | 6,624   | 9,937  | 4,138     |
| 5  | May          | 8,521    | 7,575   | 11,365 | 4,732     |
| 6  | June         | 3,886    | 3,455   | 5,183  | 2,158     |
| 7  | July         | 5,920    | 5,310   | 10,081 | 4,059     |
| 8  | August       | 8,325    | 7,401   | 11,103 | 4,623     |
| 9  | September    | 3,192    | 2,369   | 3,753  | 1,288     |
| 10 | October      | 7,234    | 6,431   | 9,647  | 4,018     |
| 11 | November     | 5,175    | 4,330   | 7,505  | 2,070     |
|    | Total        | 68,343   | 59,468  | 94,035 | 37,064    |

From Table 2, the highest defect type is a cross defect with an amount of 94,035 kg, then digest with an amount of 68,343 kg, then striped 59,468 kg, and the smallest is the type of thin ribs defect with an amount of 37,064 kg. The cause of this type of defect was stratified with the following table:

| No | Defect Types | Identification |
|----|--------------|----------------|
| 1  | Scratch      | A Type of defect on steel deformed bar surface that occur due to the hot-rolled process. |
| 2  | Line         | This type of defect is on the surface of the steel-deformed bar that forms longitudinal parallel lines of fins. |
| 3  | Cross        | A type of dimensional defect where the shape of steel deformed bar is less rounded. |
| 4  | Thin ribs    | The fin is lack of high. |

Then the frequency of product defects and defect dominance is shown in the following figures:
Figure 1 and Figure 2 show that the type of cross defect shows the most frequency and percentage of defect. Then, type of scratch defects, and line. The cumulative percentage for the 3 types of defect reached 86.3%. Figure 1 and Figure 2 show that cross defect type has the most frequency and the percentage of the defect. Then, the scratch type defect and line, respectively. The cumulative percentage of the three types of defect reached up to 86.3%. These three types of defect are sufficient for further analysis to find the solution in this study.

A Scatter diagram is used to show the relationship between product defects and total production. The Scatter Diagram of the three types of defect are shown in the following figure:

Figure 3. Scatter Diagram Cross, Scratch, and Line Defect

Figure 3 above show that the pattern formed from a scatter diagram has no relationship between defect and total production. It means that product defects will not increase or decrease if productivity is increased or decreased.

3.2 Cause-Effect Diagram (Fishbone Diagram)
Significant factors that affect the defect are analyzed by using cause and effect diagrams. The analysis is focused on the cross, scratch, and line defects. The cause and effect diagram is shown in the figures below:

Figure 4 Cause Effect Diagram (Fishbone Diagram) Cross

Figure 5 Cause Effect Diagram (Fishbone Diagram) Scratch
3.3 Analysis and Improvement

In this study, the FMEA method is used to calculate the RPN value of each impact caused by disability factors. RPN values are sorted based on the highest to the lowest value so that the causes that need the most improvement and improvement can be determined first.

| Failure Effect | S | Failure Causes                      | O  | Detection Method                  | D  | RPN  | Recommendations for Improvement                                         |
|----------------|---|-------------------------------------|----|-----------------------------------|----|------|--------------------------------------------------------------------------|
| The surface shape is not aesthetically appropriate, the product is not suitable for sale and is turned into scrap metal with low value, disrupting the smooth production line. | 7  | Top and bottom roll is not center   | 8  | Check roll with spy plate          | 6  | 336  | Add roll inspection items with spy plate into technician job list          |
|                |    | Bearing chocks worn out             | 7  | Check roll with dial indicator when mounting | 6  | 294  | Add bearing chock check items with the dial indicator into technician job list |
|                |    | Guide roll is cross                | 6  | Take a sampling for the bar size    | 2  | 84   | Check the bar size sampling before production                            |
| The technician neglected to check the spy plate | 8  | Supervise the technician intensively | 4  | 224  | Add roll inspection items with spy plate into technician job list          |
| Adjuster doesn’t check when installing the roll to the stand | 6  | Supervise the adjuster intensively  | 4  | 168  | Add roll check items into adjuster job list                              |
| New technician is still lack of skills | 5  | Supervise the new technician intensively and train them well | 4  | 140  | Practical training for new technicians                                   |
| SOP for guide installation is not implemented properly | 5  | Supervise the technician intensively | 4  | 140  | Regular briefings for technicians                                         |

In Table 4, there are six causes for the product to become cross defects. The problem that needs an immediate solution is the top and bottom roll that are not centered. Next, it is wear and tear occurs on bearing chocks, and the last one there is a technician's negligence in checking the spy plate. All six causes were recommended to solve for improvement.
In Table 5, there are seven causes of scratch defect. The highest RPN value is 448 points, where the scratch is caused by the vibrating of cooling roll while production is running. Then another cause is the presence of splinter on the worn pinch roll and caliber. All causes of this defect become recommendations to repair for improvement.

Table 5 FMEA Analysis of Steel Deformed Bar and Recommendations for Improvements to Scratch Defect

| Failure Effect | S  | Failure Causes                   | O  | Detection Method        | D  | RPN | Recommendations for Improvement |
|---------------|----|----------------------------------|----|-------------------------|----|-----|--------------------------------|
| The surface shape is not aesthetically appropriate, the product is not suitable for sale and is turned into scrap metal with low value, disrupting the smooth production line. | 7  | Vibrating cooling roll (Spindle carrier vibrates) | 8  | Checking the spindle carrier | 8  | 448 | Replace to the new Spindle Carrier |
| There is a splinter on the pinch roll | 5  | Check pinch roll regularly | 6  | Check the caliber and number of products | 7  | 392 | Change pinch roll regularly |
| Roll caliber easily wears | 8  | Water cooling roll is turn off | 2  | HMI program alarm | 1  | 14  | Do some preventive maintenance to the pumps |
| Adjuster is not appropriate to install a cooling roll | 2  | Checking a cooling roll | 3  | Supervise adjuster intensively | 4  | 140 | Add cooling roll check items into adjuster job list |
| Adjuster is less aware of physical finished product | 5  | Supervise adjuster intensively | 4  | Change pinch roll caliber design | 3  | 392 | Change the type of roll cast iron with TC ring |
| Cooling roll inspection has no SOP | 4  | Revised SOP for installing guide | 3  | Change the type of roll cast iron with TC ring | 6  | 126 | Sampling bar size before production |

In Table 6, there are seven causes of line defect. The dominant cause for a line defect is because a pinch roll caliber is too small (RPN value is 392). Another cause is the caliber roll worn out, and adjuster skill is less proficient. All causes that appear are recommended for improvement.

Table 6 FMEA Analysis of Steel Deformed Bar and Recommendations for Improvements to Line Defect

| Failure Effect | S  | Failure Causes                   | O  | Detection Method        | D  | RPN | Recommendations for Improvement |
|---------------|----|----------------------------------|----|-------------------------|----|-----|--------------------------------|
| The surface shape is not aesthetically appropriate, the product is not suitable for sale and is turned into scrap metal with low value, disrupting the smooth production line | 7  | Caliber pinch roll is too small | 7  | Checking pinch roll | 8  | 392 | Change pinch roll caliber design |
| Roll caliber worn out | 8  | Check the caliber and number of products | 7  | Supervise adjuster intensively | 4  | 140 | Regular briefings for adjuster |
| Adjuster is less aware | 5  | Supervise adjuster intensively | 4  | Practical training for adjuster | 6  | 126 | Sampling bar size before production |
| Adjuster is less proficient | 6  | Supervise adjuster intensively and train them well | 4  | Practical training for adjuster | 3  | 126 | Sampling bar size before production |
| Bar size result is not met the standard | 3  | Take sampling of bar size | 6  | Practical training for adjuster | 4  | 168 | Practical training for adjuster |

Table 6 shows that the dominant cause for a line defect is because a pinch roll caliber is too small (RPN value is 392). Another cause is the caliber roll worn out, and adjuster skill is less proficient. All causes that appear are recommended for improvement.
All recommendations suggested to the company are applied to production from March to June 2020. The results show a decrease in the percentage of product defects from 0.064 in January until November 2020 to 0.0075% (down up to 88%). Product defects are much reduced and the defect is below the maximum tolerance set by the company at 0.050%. This proves that the recommended corrective actions succeed in reducing defects so that the resulting product is more and of quality in accordance with applicable product standards.

4. Conclusion
From the results of this research, by using the SQC method through the application of seven tools and utilization of FMEA to reduce the percentage of product defects obtained the positive results. After improvement made, the percentage of product defects decreased from 0.064% to 0.0075% (decreased 88%). The highest cause of cross defects is because of uncentered between the lower and upper roll. In scratch defects, the highest RPN value comes from the Spindle Carrier that is vibrating during the rolling process. Meanwhile the big cause for a line defect is a worn calibe and pinch roll caliber is too small.

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