# Increasing the Sigma Level and Customer Value in the Manufacturing Industry: A Case Study of Cover Components

Hari Supriyanto*, Muhammad L. Reyfasha, and M. F. R. Supriyanto

Industrial and Systems Engineering Department, Faculty of Industrial Technology and Systems Engineering, Institut Teknologi Sepuluh Nopember Surabaya, Indonesia

Email: hariqive@ie.its.ac.id (H.S.); mluthfireyfasha@gmail.com (M.L.R.); ferdian.work@gmail.com (M.F.R.S.)

*Corresponding author

***Abstract*—Motorcycles have several parts, including the cover and step floor. The cover is the part that has the most defects, with a defect rate of more than 3%. The step floor cover has three types of defects, broken, untidy classification bolts, and Point black points. Based on the Pareto Chart, the most common types of defects are untidy and broken bolts. Those defects can lead to a gap between the cover step floor and the cover floor side. To overcome this problem, the Six Sigma Define, Measure, Analyze, Improvement, and Control (DMAIC) methodology can provide alternative solutions for improvement. The purpose of this paper study is to determine the feasibility of implementing alternative solutions based on the costs of alternative solutions. In the define phase, the steps consist of identifying the defect on cover parts, the production process, and the operation process chart production of the cover step floor. The measurement phase can be conducted using a Pareto chart to measure the most prevalent defects and identify the critical to quality in the production of cover parts, use a control chart to measure the Upper Control Limit (UCL), Centre line (CL), and Lower Control Limit (LCL), and calculate the Sigma Level through Defect Per Million Opportunities (DPMO). Support from finite element analysis is needed to identify stresses on the cover step floor and create alternative solutions. The analysis phase begins with the creation of a fishbone diagram to learn the root causes of defects. At the repair stage, Failure Mode and Effect Analysis (FMEA) is used to determine improvement solutions and alternatives. An alternative solution based on the highest risk priority number is used to design a tool called a jig and fixture; its function is to hold and position the cover step floor during the drilling process. The use of jigs and fixtures can increase process efficiency; there is an increase in the Sigma value and a decrease in the Defect Per Million Opportunities (DPMO) value. This proves that the use of jigs and fixtures is effective in reducing step floor cover defects and increasing customer value. The initial Sigma value was 4.1, whereas, after the implementation of alternative solutions in the form of using jigs and fixtures, the Sigma value was 4.3. This shows that alternative solutions can increase the production efficiency of the cover step floor; there was a decrease in DPMO from 4,660 to 2,550.**

***Keywords*—defect, Six Sigma DMAIC, Failure Mode and Effect Analysis (FMEA), jig and fixture**

## I. INTRODUCTION

One of the products of the automotive industry that is in great demand is motorcycles. There are more than 125 million motorcycle users in Indonesia. The number of motorcycle users also increases annually. The increase in motorcycle users in Indonesia is very significant. This proves that motorcycles are vehicles that are in great demand in Indonesia.

There are several plastic parts on a motorcycle, and the cover is one of the most important plastic parts. The cover for this part of the motorcycle consists of a step floor cover, floor side cover, front side cover, and lid pocket cover. On motorcycles, there is a body frame that forms the backbone of the cover. The body frame and the closing parts are interconnected with each other. If there is a defect in one of these components, it can result in a defect, especially on the cover, which has many variations.

Therefore, this study analyzes the defects of the cover component and makes improvements to reduce the defects [1]. With the use of quality control, problem identification can be overcome, resulting in fewer defects. Quality control is a system that maintains the desired level of quality by providing feedback on product or service characteristics and implementing corrective actions when these characteristics deviate from the specified standards [2, 3]. To obtain quality products, quality control is a way to improve product quality. Quality control is implemented so that the industry produces products that meet consumer product standards [4]. This motor has problems with cover parts, especially on the cover floor step and cover floor side; usually, there is a gap in the two cover parts that should be attached to each other. The floor step cover is the part that serves to place the user's feet when using the motorbike. The floor side cover is the plastic part of the motorbike that supports the floor step cover and protects

Manuscript received July 26, 2023; revised September 7, 2023; accepted October 17, 2023; published January 24, 2024.

doi: 10.18178/ijmerr.13.1.26-34

the body frame at the bottom of the motorbike, as shown in Fig. 1.

Problems on the cover step floor can be caused by several factors, namely, the trimming process, assembly, and operator error. There are three types of defects in the cover step floor: broken, bolts on the cover that are not neat, and black dots. The Six Sigma methodology is used to solve the problem. Six Sigma is an extension of a quality control method that aims to improve quality and productivity, reduce defects, minimize costs, reduce processing time, and increase customer value and satisfaction [5, 6].


Fig. 1. Cover the step floor and cover the floor side.

There are two Six Sigma methods Define, Measure, Analyze, Improvement, and Control (DMAIC) and Define, Measure, Analyze, Design, and Verify (DMADV) [7]. Both methods can be used for process improvement (DMAIC) and tools for creating new designs or improving existing designs (DMADV) [8, 9]. The cover step floor is a component that has the main problem, which is a gap between the cover step floor and the cover floor side. The problem occurs because the shape of the cover step floor is complex, which makes the production process a bit more complicated than other cover parts. The problem of the cover floor step can be caused by several factors, including the trimming process, the assembly process, and the operators. The Six Sigma DMAIC methodology can be used to improve quality and reduce defects. There are several methods included in the Six Sigma DMAIC. In the define phase, the critical to quality is used as a tool to identify the key characteristic of the cover step floor that may cause the defect. The control chart is used to distinguish the upper control limit, control limit, and lower control limit to monitor measurement activity and determine if there are deviations or irregularities. In the measure phase, the Pareto chart is used to identify the most important or frequent causes of a cover step floor defect. The fishbone diagram is used to distinguish the cover step floor's most important or frequent causes of a particular problem or situation. In the analysis phase, Finite Element Analysis (FEA) is a method to identify the behavior of the cover step floor when a load is applied to determine the right pressure needed for the jig and fixture for the cover step floor. In the improvement phase, the failure mode effect analysis is used to identify and prevent cover step floor problems before they occur. Finally, in the alternative solution phase, the jig and fixture will be designed using 3D software.

## II. Literature Review

### A. *Quality*

Automotive is anything that spins by itself. The word automotive itself comes from the words "auto" and motif which mean "self" and "reason". Automotive is basically the study of vehicle systems. The automotive industry is a company that manufactures motor vehicles and their components, such as engines and body parts, as well as sells and maintains vehicles [9, 10]. In short, the automotive industry designs, manufactures, and sells the means of transportation that we use every day, such as motorcycles and cars. To do so, companies need to efficiently manage production resources and all other factors that can generate profits with minimal losses. Losses in the automotive industry can occur from many factors, such as a lack of quality control, immature business processes, and a lack of parts suppliers [1].

Quality is the characteristic of a product or service that can satisfy customer needs [11]. Quality is the totality of features and characteristics possessed by a product that can satisfy consumer needs. It can be concluded that quality is about customer satisfaction and values; therefore, quality basically must always be improved continuously. To improve and maintain the quality of products or services there are several quality indicators to consider [12]:

1. Performance means that the characteristics of the product are in line with the performance of the product itself. This indicator refers to the customer's perspective that attributes can be measured through the voice of the customer.
2. Features mean that the product has secondary performance aspects or additional performance that makes the product better.
3. Reliability is the probability of the product working or not working properly.
4. Conformity is a metric used to assess how well a product meets various requirements or specifications.
5. Durability means the age of a product until it needs to be replaced.
6. Serviceability refers to the ease with which the product can be serviced or repaired if necessary. This is usually related to the after-sales service provided by the manufacturer, such as the availability of spare parts and ease of repair if damage occurs, as well as the existence of a service center that is easily accessible to consumers.
7. Aesthetics is a subjective view of product appearance in the form of the design, taste, sound, and smell of the product. Aesthetics from a person's point of view vary depending on consumer tastes.
8. Perceived quality is the impression of the quality of a product that consumers feel.

### B. *DMAIC*

Six Sigma is a strategy for identifying and describing defects in the manufacturing process that are burdensome with respect to time, money, customers, and opportunities [13]. Meanwhile, according to reference [14], Six Sigma is a fact-driven, data-driven improvement philosophy that emphasizes defect prevention over defect detection. This can increase customer value and satisfaction by lowering variation and waste, resulting in a competitive advantage. Six Sigma has been defined as a concept that applies a well-structured continuous improvement approach to minimize process variability and waste in business operations via the use of statistical tools and methodologies [15]. Six Sigma refers to operational performance objectives that are statistically measured to have less than 3.4 defects per million opportunities [16]. In percentages, the Six Sigma process for a product without defects is 99.99966%.

Six Sigma has two methods: DMAIC and DMADV. DMAIC is a data-based quality strategy that is used to improve a production process or service. These methods are implemented as standalone quality improvement procedures or as part of other process improvement initiatives. Meanwhile, DMADV is a quality strategy used when a client or consumer needs a product improved, or adjusted, or a whole new product or service created [17].

## III. Methodology

The methodology begins with the defining phase, the identification and formulation of the problem, and the identification of the existing conditions on the product cover part. Data collection consists of the defined phase, which includes steps to identify defects in cover parts, cover part production processes, and Critical to Quality (CTQ). This defining phase consists of identifying defects in the cover part and identifying the cover part production process. The second step is to identify the production process of the cover part, namely, by observing the production process of plastic injection. The third step is to make an operation process chart to see the production flow in more detail.

The measure phase includes steps for measuring defects using Pareto diagrams and measuring upper control limits, control limits, and lower control limits using control charts. The Sigma Level measurement is performed for existing conditions.

The analysis phase analyzes the root causes of defects in cover parts using the fishbone diagram, which consists of six aspects, namely, man, material, machine, method, measure, and environment, and five whys sequentially to identify critical root causes.

The improvement phase includes an analysis of potential failures and their consequences using the Failure Mode and Effect Analysis (FMEA) method by determining the severity, occurrence, and detection values and calculating the Risk Priority Number (RPN) by multiplying all FMEA factors, followed by determining alternative improvements based on the highest RPN value and proposing alternative solutions [18]. Finally, validation of alternative solutions and calculation of the Sigma value in improvement conditions, as well as calculation and analysis of the cost of implementing alternative solutions using the BCR ratio, net present value, and payback period [19].

In the control phase, we will explain the design of the Standard Operating Procedure (SOP) for the operation of jigs and fixtures and how they differ from the SOP before improvement is performed [20]. Methodological stages can be seen in Fig. 2.

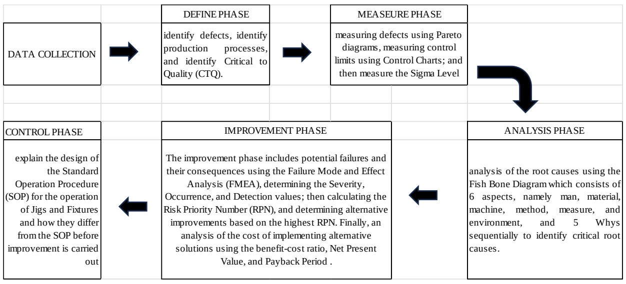


Fig. 2. Research methodology.

## IV. Result

To determine product defects, supporting data is needed that can describe and identify the product, as shown in Figs 3 and 4. The data covers the part defect data which consists of the cover step floor, cover side floor, cover lid pocket, and cover front side.

Table I shows the cover part data, and Table II shows the type and number of defects.

TABLE I. Dimension of Cover Step Floor

| Description | Size (mm) | | Description | Size (mm) |
|---|---|---|---|---|
| Over hole dimension per unit | 10 | | Front height length | 260 |
| The overall length of the cover step floor | 390 | | Cut shape depth | 27 |
| Rear side angle display | 170 | | Cut rectangle width | 41 |
| Top curved length | 240 | | Cut rectangle length | 53 |
| Curved angle of each unit | $\geq 30°$ | | Relevant angle | 18 |
| Footrest width | 105 | | Hole dimension per screw unit | 7 |
| Cover step floor height length | 170 | | Cut rectangle dimension length | $13 \times 5$ |
| Rear arm length | 240 | | Cut rectangle diameter | 16 |
| High height length | 540 | | Cut rectangle angle | 110° |

The above data are the basis for determining the points that cause defects.

By finding these points, the jig and fixture design can be used to reduce or even eliminate defects that appear.

### *A. Define Phase*

The define phase is used to determine the cover part problem. The steps include identifying the defects in the cover component, the production process, and the CTQ. There are several types of defects such as broken, untidy bolts and black dots. The classification of broken and untidy bolts on the cover part can be caused by the operator or the production process. One of the production processes that can cause broken and untidy grouping of bolts is the trimming process; this occurs when the cover is tidied up and performed manually. Black dots are generally caused by the molding process after the smelting process.

As a result of melting, an eruption of plastic pellets can occur, and this eruption melts to form a black dot. There are several production processes for part covers, namely, plastic injection, smelting processes, molding processes, trimming processes, painting processes, stripping processes, and assembly processes.

TABLE II. TYPE AND NUMBER OF DEFECTS OF COVER PARTS

| | **Period** | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | Total |
| Product production-pp (unit) | 21,700 | 24,900 | 25,250 | 26,750 | 28,300 | 32,300 | 29,850 | 30,750 | 31,800 | 32,600 | 34,250 | 29,250 | 347,700 |
| Cover step floor-CSF (unit) | 263 | 193 | 134 | 214 | 144 | 162 | 236 | 158 | 208 | 115 | 173 | 151 | 2,151 |
| % CSF/pp | 1.05 | 0.78 | 0.53 | 0.80 | 0.51 | 0.50 | 0.79 | 0.51 | 0.65 | 0.35 | 0.51 | 0.52 | 7.5 |
| Cover floor side-CFLS (unit) | 152 | 130 | 109 | 99 | 166 | 188 | 192 | 117 | 184 | 93 | 128 | 106 | 1,664 |
| % CFLS/pp | 0.70 | 0.52 | 0.43 | 0.37 | 0.59 | 0.58 | 0.64 | 0.38 | 0.58 | 0.29 | 0.37 | 0.36 | 5.81 |
| Cover front side-CFRS (unit) | 51 | 28 | 24 | 33 | 40 | 55 | 67 | 34 | 46 | 21 | 49 | 22 | 470 |
| % CFRS/pp | 0.30 | 0.10 | 0.10 | 0.10 | 0.10 | 0.30 | 0.30 | 0.10 | 0.10 | 0.10 | 0.10 | 0.10 | 1.80 |
| Cover lid pocket-CLP (unit) | 12 | 25 | 13 | 6 | 17 | 22 | 30 | 8 | 23 | 12 | 5 | 3 | 176 |
| % CLP/pp | 0.00 | 0.10 | 0 | 0 | 0 | 0.10 | 0.10 | 0 | 0.10 | 0 | 0 | 0 | 0.40 |

## *B. Measure Phase*

At the measure phase, most defects are measured on the cover step floor. The dimensions of the cover step floor are required, as shown in Table II. The types of defects identified were broken, untidy bolts, and black dots. Most defects can be measured on the cover step floor using the Pareto chart, as shown in Fig. 3. There are two production processes that are the main problems in the cover step floor, namely, the trimming process and the assembly process. Both production processes are conducted by operators. Below, CTQ will show the main problems with the cover step floor.

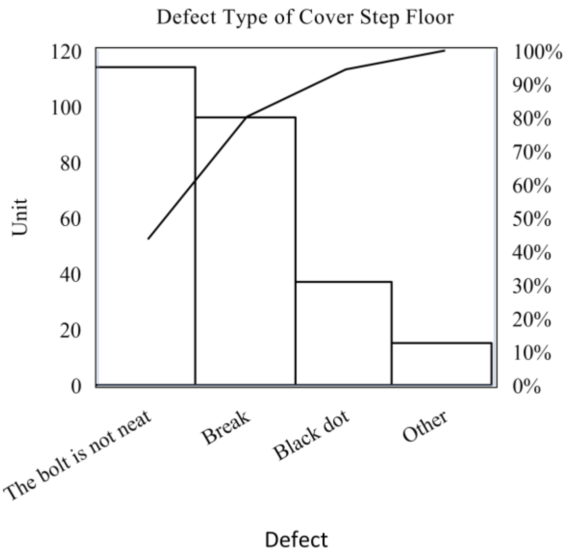


Fig. 3. Pareto chart of the cover step floor.

Based on the CTQ formed, the main problems with the cover step floor are the trimming process, the assembly process, and the operator. The CTQ results show that the processes of trimming part covers, bolt classification, and assembling of cover step floors and cover side floors need to be performed more neatly so that cover step floors and cover floor sides can be installed perfectly. Based on the defect data, the depiction of defects in the production process is conducted using a p-chart control chart, and SPSS software is used to describe it in the form of a p-chart. The result of the p-chart is shown in Fig. 4.

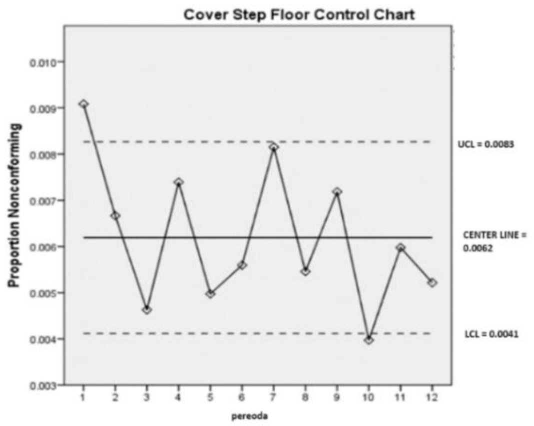


Fig. 4. Cover step floor control chart.

The Sigma Level calculation starts with the calculation of the defects per unit, followed by the calculation of the defects per opportunity so that DPMO can be obtained. Sigma Level is calculated for the classification of untidy and broken bolts. The DPMO results will be used to calculate the Sigma value using Microsoft Excel with the formula,

NORMSINV = (1000000−5230414747) / 1000000 + 1.5

The Sigma Level value obtained for the current condition is 4.1 Sigma.

To determine the causes of defects in the product, a FEA is needed. This analysis is a method to identify the exact pressure needed for the cover step floor when it is pressed, as shown in Fig. 5 and Fig. 6. This pressure causes defects in the cover step floor. To reduce defects, a jig and fixture will be designed for holders and fixers for the drilling process.

There are two FEAs, namely, the FEA for closing the footing floor when drilled and the FEA for closing the footing floor when pressed with a jig and fixture.

The two steps of FEA will be the same: creating a study is used to determine what the material is made of (high-density polyethylene); a yield strength safety factor is used to confirm whether there is damage or not when adding the input force and pressure at the load point; a mesh view is used to create a mesh showing where the strengths are, and finally, the simulation from the FEA outputs as a PDF. For the required step floor cover size, a 2D sketch was created, and a 3D cover step floor was designed, as shown in Fig. 7. If there is an error in the 3D design, a trial-and-error analysis is performed to determine whether it matches the original shape (fillet, hole, revolve, plane, extrude) [21].

Fig. 5. Cover step floor upside view.

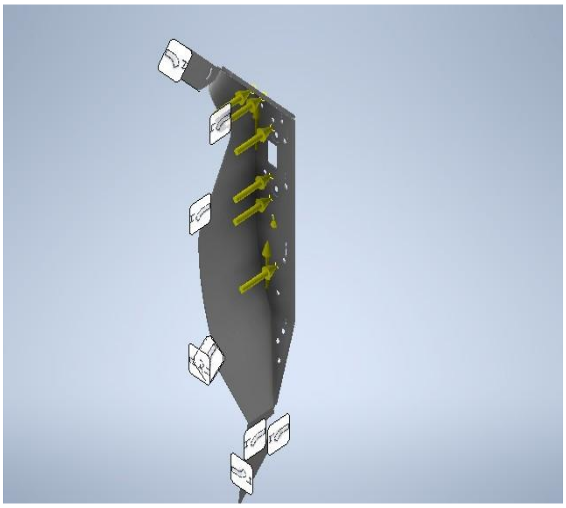

Fig. 6. Faces or parts that are being pressed (drill).

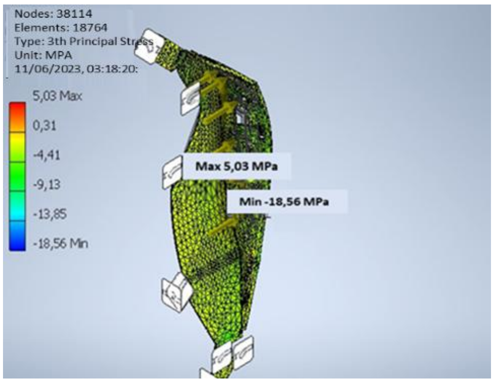


Fig. 7. Third principal stress result (drill).

After all steps are completed, FEA can be analyzed. There will be two FEA analyses, namely the FEA of the footing cover when it is drilled and the FEA of the footing cover when it is pressed with a jig and fixture. The two steps in FEA are the same: creating a study is used to determine the material; a yield strength safety factor is used to confirm whether damage has occurred, adding input force and pressure at the point of load; a mesh view is used to create a net that shows where the strength and finally, the finite element simulation [1]. FEA is conducted to cover the step floor to the drill to see how much pressure is needed by the drill when dividing the bolt pressure. The pressure on the drill also has an impact on defects in the cover step floor. If the resulting bolt classification is not perfect, then the installation on the cover step floor and cover floor side will not be perfect, or there will be gaps between the two covers. Displacement results show the results of changes in the shape of the cover step floor after the loading is applied to the cover step floor, as shown in Fig. 8.

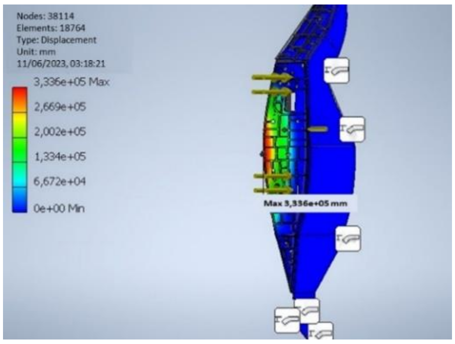


Fig. 8. Displacement result (drill).

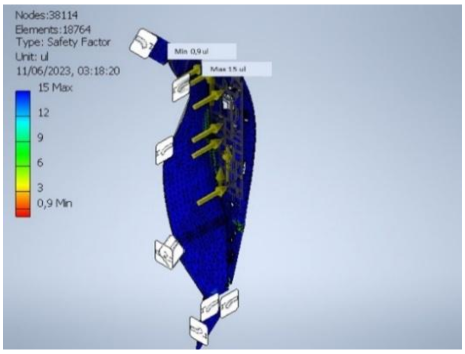


Fig. 9. Safety factor result (drill).

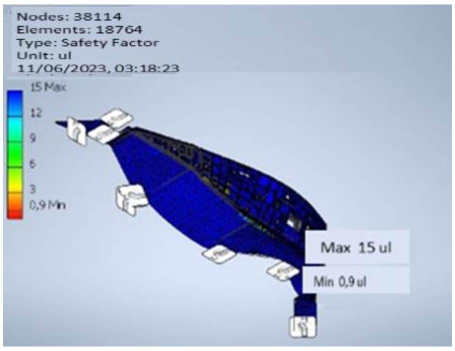


Fig. 10. Safety factor (jig and fixture).

The color indication is blue, which means that if the cover step floor is pressed with 15 MPa, the cover step floor will not be damaged or broken. Based on the displacement result, as shown in Fig. 8, the minimum distance from the drill to the cover step floor is 0 mm, which means that there is no load that presses the cover step floor and the maximum is 7.52 mm from the drill to the cover step floor when there is a load that presses the cover step floor

If the pressure is more than 15 MPa, then the cover step floor has the potential to be damaged or broken when held by the jig and fixture. Meanwhile, if the pressure is below 0.9 MPa, then there is a potential for the cover step floor not to be held properly, which can cause shifting of the cover step floor when attached to the jig and fixture, as shown in Fig. 9. For the drill if the drill presses the cover step floor with 15 MPa, the drill will perfectly drill the cover step floor and will not damage the jig and fixture underneath the cover step floor. Meanwhile, if the pressure is below 0.9 MPa, then there is a potential that the cover step floor is not being drilled correctly, as shown in Fig. 10. The safety factor results based on safety pressure are needed when the jig and fixture press the step floor cover. This is an important safe parameter of the allowable stress with the applied stress from the drill to the jig and fixture. The image above indicates a blue color, which means that if the cover step floor is pressed, it will not be damaged or broken [22].

### *C. Analysis Phase*

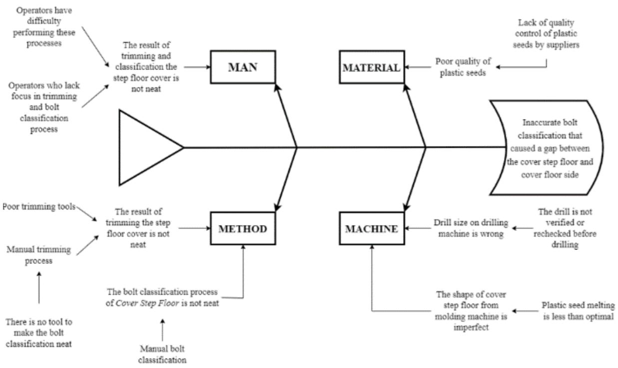


Fig. 11. Fishbone diagram.

The analysis phase begins with the creation of a fishbone diagram, which includes six aspects, namely, man, material, machine, method, measure, and environment. This fishbone diagram is based on the Pareto chart and is specifically for trimming processes where there are loose and broken bolts [23]. The main cause of defects in the step floor cover is that the step floor cover and side floor cover are not installed properly. A fishbone diagram can be seen in Fig. 11.

The material of the cover step floor can be one of the causes of the defect in the cover step floor; this material comes from plastic seeds. The company cannot ensure the quality of the plastic seeds and is only based on supplier quality control. Poor-quality plastic seeds can cause the floor step cover to have low durability and make the cover parts break easily.

The other factor that can cause a defect on the cover step floor is the machine. The machine that can cause the defect is when the drill size on the machine is wrong. This can cause defects in the cover step floor bolt. The result of a wrong drill to bolt will cause the cover step floor to not be assembled with the cover floor side because the size of the bolt classification is not according to the standard. This problem occurred because the drill was not verified or rechecked before drilling.

The shape of the cover step floor is imperfect because of the molding machine. The imperfect shape of the cover step floor can be caused by a lack of mold maintenance. The mold in the molding process really affects the cover step floor shape. In addition, insufficient temperature control during the smelting process affected the shape of the cover step floor.

In the trimming process, there are two processes: the cover step floor and the bolt classification on the cover step floor. Both processes are still performed manually using a trimming tool and a drill for bolt classification. Because the process is performed manually, human errors will occur, such as the operator having difficulty completing the process and being less focused during the process. Lack of operator focus can occur due to the seriousness and accuracy of the operator, resulting in defects in the cover step floor.

The trimming process of covering the step floor is performed manually by the operators. The manual trimming can cause a defect on the cover step floor. In addition, the tools that are being used by the operators are old trimming tools, which can be considered poor trimming tools. The classification bolt is also performed manually by the operators using a drill, human errors in this process can occur. The classification bolt is not neat, which can occur because there are no tools to hold the cover step floor.

A difficult measurement is when measuring the holes in the bolt classification on the cover step floor. This bolt classification is used to attach the cover step floor to the cover floor side. The standard diameter of the holes in the cover step floor, according to the company's standard, is 11 mm. To obtain 11 mm in the holes for the bolts, the operator cannot be sure directly about the bolt. Therefore, defects can still occur and cause a gap between the cover step floor and the cover floor side.

The environment inside the factory greatly affects the focus of the operators. One of the environmental factors is noise; this can reduce the operator’s focus, especially on the bolt classification process, which is performed manually and causes defects in the step floor cover components.

### D. Improvement Phase

A failure mode effect analysis is designed to analyze the potential failure of a defect. There are several factors in FMEA, namely, potential failure mode, potential effects, and control. Alternative improvements were obtained from the calculation of the value of the RPN. The RPN value is obtained by multiplying the severity (S), occurrence (O), and detection (D) rates. Severity is how much the failure feels to the customer, impact of failure by evaluating its failure mode and assign a score for severity in case of failure (0–10), occurrence is how often a failure occurs, or frequency of possible risk occurrence, evaluate and assign a score to the possibility of failure (0–10) and detection is the chance of a failure being detected and assign a score to the likelihood that control can detect the cause of failure (0–10). The severity, occurrence, and detection ratings are shown in Table III.

TABLE III. FAILURE MODE EFFECT ANALYSIS

| No. | Potential Failure Mode | Potential Effect | S | Potential Causes | O | Control | D | RPN | Recommended Action | Action Taken |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Bolt classification is not neat | Defects that occur in the die, trimming, drilling process, and assembly process of the cover step floor | 9 | The bolt classification process is still performed manually | 8 | Planning tools in the bolt classification process and making SOPs | 9 | 648 | Manufacture of tools for the bolt classification process | Designing jigs and fixtures to make it easier for operators to perform the bolt classification process |
| 2 | The bolt point on the cover step floor of the die | | 2 | Maintenance of the die is not executed regularly | 2 | Maintenance planning for die | 2 | 8 | Preventive maintenance of die | Preventive maintenance on a die is performed every time to reduce potential defects |
| 3 | Bolt size that does not meet the standard | | 10 | The bolt process is still conducted manually | 7 | Planning tools in the bolting process and making SOPs | 9 | 630 | Manufacture of tools for the bolt classification process | Designing jigs and fixtures to make it easier for operators and making SOPs to use the tool |
| 4 | The drill size on the drilling machine is wrong | | 7 | The drill is not verified or rechecked before drilling | 4 | SOP planning for verification of the drill size to be used | 9 | 252 | Making SOP in verifying drill size before pairing with drill machine | The SOP is made in detail and easily understood by the operator so that the drill is verified with the size |
| 5 | There is a gap between the cover step and the cover floor | | 9 | The bolt classification process is still performed manually | 8 | Planning tools in the bolt classification process and making SOPs | 9 | 648 | Manufacture of tools for the bolt classification process | Designing jigs and fixtures to make it easier for operators and making SOPs to use the tool |
| 1 | The cover step floor broke after the bolting process | Defects that occur in the trimming process affect die results | 6 | The sound of machines near the trimming process | 4 | Application of control engineering for industrial noise | 4 | 96 | Engineering control for industrial noise analysis is performed for each machine | Sound absorbers are used for machines that are noisy, and operators use earmuffs |
| 2 | The cover Step Floor broke after trimming the cover step floor | | 6 | Operator negligence during the trimming process | 5 | SOP planning and training for operators | 4 | 120 | Making SOPs in the trimming process and conducting training on operators regularly | Creating SOPs that are easier for operators to understand so that operator negligence can be reduced |
| 3 | Poor trimming tools | | 4 | No regular maintenance | 2 | Maintenance planning for trimming tools | 4 | 32 | Preventive maintenance of the die is performed regularly | Preventive maintenance is performed every shift to reduce potential defects per shift |

Notes: S: severity, O: occurrence, D: detection

Based on failure mode effect analysis, there are three potential failure modes that have high RPN according to severity, occurrence, and detection. The first potential failure that has a high RPN is the untidy bolt classification. This failure potential occurs in the trimming process, especially in the bolt classification process, and is performed manually. The second potential failure is the bolt size, which is not up to standard. The third potential failure is that there is a gap between the cover step floor and the cover floor side during assembly. This shows that the potential cause of the three failure modes is the bolt classification process, which is still performed manually. Therefore, the control of the three potential failure modes is the design of tools in the form of jigs and fixtures to simplify operator activities. This jig and fixture are used in the trimming process, especially to hold the cover step floor when it is drilled so that the operator does not need to hold the cover step floor correctly [24], as shown in Fig. 12.

Then it is calculated and compared to the initial value sigma value for improvement, as shown in Table IV.

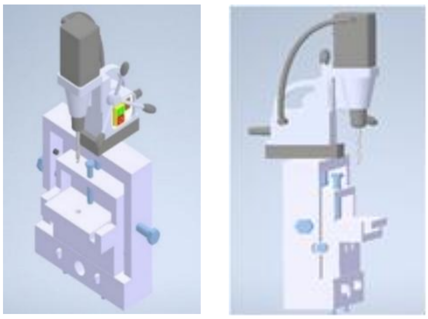

Fig. 12. The jig and fixture full design is attached to the drilling machine.

TABLE IV. COMPARISON OF INITIAL SIGMA VALUE WITH SIGMA VALUE IMPROVEMENT

| Condition | No. of Production | No. of Defects | DPMO | Sigma Value |
|---|---|---|---|---|
| Existing condition | 21,700 | 227 | 4,660 | 4.1 |
| Improvement condition | 21,700 | 114 | 2,550 | 4.3 |

### *E. Calculation and Analysis of the Cost of Implementing Alternative Solutions*

At this phase, the calculation and analysis of the investment costs of the jig and fixture design are performed. This cost calculation is seen from three aspects, namely, BCR, net present value, and payback period. To determine whether the investment is good or not, the following are the categories of good investment criteria: (1) the BCR value is greater than 1, and (2) the net present value is positive 3. The payback period is not more than 5 years. Table V shows the calculation of the present value of expected benefits using Microsoft Excel.

Then, the benefit-cost ratio is calculated as follows:

$$BCR = (334857710) / (45411430) = 7.37$$

The BCR result is 7.37 more than 1. This shows that the alternative solution to jig and fixture is profitable.

Using Microsoft Excel, Table V calculates the net present value as NPV = IDR 289,446,280 (positive).

This shows that the costs incurred for jig and fixture investment are profitable.

The calculation of the payback period obtained a value of 0.586734902 which if converted into months, is 7 months, meaning that the investment will return after the seventh month, not up to 1 year.

TABLE V. PRESENT VALUE EXPECTED BENEFITS CALCULATION

| Present Value Expected Benefits Calculation | | | | | | | |
|---|---|---|---|---|---|---|---|
| Description | Periods | | | | | | Total |
| | 0 | 1 | 2 | 3 | 4 | 5 | |
| Investment in jig and fixture | 45,411,430 | | | | | | |
| Total expenses | | 27,255,155 | −28,345,362 | 29,479,176 | −30,658,343 | 31,884,677 | |
| Profit | | 77,396,845 | 76,306,638 | 75,172,824 | 73,993,657 | 72,767,323 | |
| | | | | | | | |
| Cash flow | 45,411,430 | −31,985,415 | 108,292,053 | 183,464,877 | 257,458,534 | 330,225,857 | |
| | | | | | | | |
| Present value | | 74,420,043 | 70,549,777 | 66,828,367 | 63,250,088 | 59,809,435 | 334,857,710 |

### *F. Control Phase*

At this phase, an SOP will be designed for the use of jigs and fixtures. The SOP contains instructions on how operators can operate jigs and fixtures properly and correctly, from set-up to the drilling process [25].

There are significant differences in procedures that must be conducted by operators. If previously the operator performed a lot of manual activities that required a long time, in the SOP using a jig and fixture, the operator only placed the part into the jig and fixture. After that, the drilling process was executed by pulling the lever, and the drilling operating process became faster. This procedure will be able to reduce defects and increase customer value [6].

## V. CONCLUSION AND SUGGESTION

1. There was a gap between the cover step floor and the cover side floor because the bolts on the cover step floor were not neat, so the cover step floor and cover side floor were not installed properly.

2. In the existing condition, the Sigma value is 4.1. After implementing alternative solutions in the form of jigs and fixtures, the Sigma value increases to 4.3. This shows that an alternative solution for jig and fixture design can increase production efficiency and decrease defects in the cover step floor.

3. Several financial calculations can be used as a final decision, namely, the benefit-cost ratio (BCR), which indicates a value of more than 1. Then, the NPV obtained is positive, indicating good, and the payback period obtained a value of 0.58 or approximately 7 months, which indicates that the investment will return after 7 months. From these outputs, it can be concluded that investment in this alternative solution is very profitable for improvement.

Suggestions for future research are advised to analyze the capability of alternative solutions and the ergonomic safety of this jig and fixture.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

Hari Supriyanto contributed to all research activities, starting with conducting research, analyzing data, and writing papers; Muhammad L. Reyfasha and Mohammad F. R. Supriyanto performed the data analysis and wrote the papers; all authors have approved the final version of the manuscript.


## ACKNOWLEDGEMENTS AND DISCLAIMER

This study was developed in the context of the motorcycle. The authors thank the Industrial and Systems Engineering Department, Faculty of Industrial Technology and Systems Engineering, Sepuluh November Institute of Technology, Surabaya, for all their support until the completion of this paper.


## REFERENCES


[1] A. Pacana, K. Czerwinska, and R. Dwornicka, "Analysis of quality control efficiency in the automotive industry," *Transp. Res. Procedia*, vol. 55, pp. 691–698, 2021, doi: 10.1016/j.trpro.2021.07.037.

[2] A. O. Adeodu, M. G. Kanakana-Katumba, and R. Maladzhi, "Implementation of lean Six Sigma (Lss) methodology, through DMAIC approach to resolving downtime process; a case of a paper manufacturing company," in *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, vol. 59, pp. 37–47, 2020.

[3] M. A. Omprakas, *et al.*, "Analysis of shrinkage defect in sand casting by using Six Sigma method with Taguchi technique," in *Proc. IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1059, no. 1, 2021, doi: 10.1088/1757-899X/1059/1/012047.

[4] G. Gupta and R. P. Mishra, "Identification of critical components using ANP for implementation of reliability-centered maintenance," *Procedia CIRP*, vol. 69, no. May, pp. 905–909, 2018, doi: 10.1016/j.procir.2017.11.122.

[5] I. C. B. Rosa, T. R. Damayanti, A. L. Kusumaningrum, and S. S. Islam, "Product defects analysis using Six Sigma method – a case study at rice milling company," in *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, 2021, pp. 158–169.

[6] J. Martin, M. Elg, and I. Gremyr, "The many meanings of quality: towards a definition in support of sustainable operations," *Total Qual. Manag. Bus. Excell.*, vol. 0, no. 0, pp. 1–14, 2020, doi: 10.1080/14783363.2020.1844564.

[7] K. Phusavat and R. Kanchana, "Future competitiveness: viewpoints from manufacturers and service providers," *Ind. Manag. Amp; Data Syst.*, vol. 108, no. 2, pp. 191–207, 2008, doi: 10.1108/02635570810847572.

[8] R. Acero, M. Torralba, R. Pérez-Moya, and J. A. Pozo, "Value stream analysis in military logistics: the improvement in order processing procedure," *Appl. Sci.*, vol. 10, no. 1, 2020, doi: 10.3390/app10010106.

[9] V. Sunder M, S. Mahalingam, and S. N. Krishna M, "Improving patients' satisfaction in a mobile hospital using Lean Six Sigma–a design-thinking intervention," *Prod. Plan. Control*, vol. 31, no. 6, pp. 512–526, 2020, doi: 10.1080/09537287.2019.1654628.

[10] K. Purushothaman and R. Ahmad, "Integration of Six Sigma methodology of DMADV steps with QFD, DFMEA and TRIZ applications for image-based automated inspection system development: a case study," *Int. J. Lean Six Sigma*, vol. 13, no. 6, pp. 1239–1276, 2022, doi: 10.1108/IJLSS-05-2021-0088.

[11] A. O. Adeodu, M. G. Kanakana-Katumba, and R. Maladzhi, "Implementation of lean Six Sigma (Lss) methodology, through DMAIC approach to resolving downtime process; A case of a paper manufacturing company," in *Proc. Int. Conf. Ind. Eng. Oper. Manag.*, vol. 59, no. February, pp. 37–47, 2020.

[12] L. C. Hoe and S. Mansori, "The effects of product quality on customer satisfaction and loyalty: evidence from the Malaysian engineering industry," *Int. J. Ind. Mark.*, vol. 3, no. 1, p. 20, 2018, doi: 10.5296/ijim.v3i1.13959.

[13] J. Jiang and T. Nguyen, "Process improvement by application of Lean Six Sigma and TRIZ methodology case study in the coffee company," *Int. J. Appl. or Innov. Eng. Manag.*, vol. 4, no. 3, pp. 208–219, 2015.

[14] H. De Koning and J. De Mast, "A rational reconstruction of Six-Sigma's breakthrough cookbook," *Int. J. Qual. Reliab. Manag.*, vol. 23, no. 7, pp. 766–787, 2006, doi: 10.1108/02656710610701044.

[15] N. Jamil, H. Gholami, M. Z. M. Saman, D. Streimikiene, S. Sharif, and N. Zakuan, "DMAIC-based approach to sustainable value stream mapping: towards a sustainable manufacturing system," *Econ. Res. Istraz.*, vol. 33, no. 1, pp. 331–360, 2020, doi: 10.1080/1331677X.2020.1715236.

[16] A. Adeodu, M. G. Kanakana-Katumba, and M. Rendani, "Implementation of lean Six Sigma for production process optimization in a paper production company," *J. Ind. Eng. Manag.*, vol. 14, no. 3, pp. 661–680, 2021, doi: 10.3926/jiem.3479.

[17] M. Soković, J. Jovanović, Z. Krivokapić, and A. Vujović, "Basic quality tools in the continuous improvement process," *Stroj. Vestnik/J. Mech. Eng.*, vol. 55, no. 5, pp. 333–341, 2009.

[18] A. Sutrisno and T. Lee, "Service reliability assessment using failure mode and effect analysis (FMEA): Survey and opportunity roadmap," *Int. J. Eng. Sci. Technol.*, vol. 3, no. 7, 2012, doi: 10.4314/ijest.v3i7.3.

[19] V. Tandel, V. Yadav, A. Shrivastav, T. P. Singh, B. Chauhan, and A. Shaikh, "Reducing casting defects in foundry industry by using Six Sigma methodology," *Int. Res. J. Eng. Technol.*, pp. 3939–3952, 2020, [Online]. Available: www.irjet.net

[20] H. Al Haiany, *Reliability Centered Maintenance Different Implementation Approaches*. Luleå University of Technology, Sweden, 2016.

[21] J. Savaliya and H. Parikh, "3D printing technology : A future perspective," *International Journal Eng. Res. Electron. Commun. Eng.*, pp. 12–17, 2021.

[22] F. E. Analysis and C. Bracket, "Ences Refer," pp. 1–3, 2015.

[23] M. Coccia/ (2018). The fishbone diagram to identify, systematize, and analyze the sources of general purpose technologies," *J. Soc. Adm in. Sci.*, vol. 4, no. 4, pp. 291–303. [Online]. Available: https://ssrn.com/abstract=3100011Electroniccopyavailableat:https://ssrn.com/abstract=3100011Electroniccopyavailableat:https://ssrn.com/abstract=3100011.

[24] V. Kumbhar and H. C. Pandit, "A review article on jigs and fixture Jayesh," *Design. Jigs, Fixtures Press Tools*, vol. 6, no. 6, pp. 633–636, 2017.

[25] K. Venkataraman, "Design of jigs, fixtures, and press tools," *Des. Jigs, Fixtures Press Tools*, pp. 3–8, 2022, doi: 10.1007/978-3-030-76533-0.