Bolt Product Quality Control Using Six Sigma DMAIC Method (Case study: PT XYZ Company)

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Abstract. The main purpose of quality control is to increase customer satisfaction. PT XYZ is one of the companies engaged in manufacturing by producing bolt product. In terms of quality control, the company is still getting products that increase customer satisfaction and exceed the company's limits with a defect rate of 13.72%. From the analysis using the DMAIC and FMEA methods, there are 2 (two) dominant types of CTQ bolt products, namely screw defects and bolt head defects. The factors that cause Bolt product damage are: The company's DPMO value is 45,744 and the $\sigma$ value is 3.19, which means that it is still far from the industry level in the world which reaches 6 $\sigma$ (3.4 DPMO). The company’s highest Risk Priority Number (RPN) is 265 which is caused by a less than optimal engine condition (dirty dies, shifted dies, and worn dies).

Proposals to improve the quality of bolt products using the Six Sigma and FMEA methods for the company, namely check the condition of the machine, and make sure the dies engine is in a proper condition to operate.

1. Introduction

The rapid development of industry requires the application of science and technology balanced according to the desired needs. With the rapid development technology, the resulting competition between companies continues to increase. These conditions encourage every company to improve the quality of the products produced. Company make consumers or customers as product users as a reference for product success which has been produced by the company [1]. On the off chance that the consequences of QC tests can't satisfy the acknowledgment models, the aftereffects of examination of the entire arrangement of the estimations on that day must be eliminated or should be re-dissected, and an incomplete or full re-approval of the strategy considered [20].

PT XYZ is one of the companies engaged in manufacturing by producing spare parts of metal bolt, nut and rubber seal material. In this case, the product that will be selected as the object of research is the metal bolt product because this product has the highest defects. The bolt product consists of 4 components namely bolt head, bolt body, thread and nut. Based on observations obtained by PT XYZ experienced waste (product) on the product that is a defect in the form of diameter defects, screw defects, as well as defects in terms of bolt head that are not in accordance with the specified standards resulting in losses for the company. Data on the number and percentage of product defects wooden pallet during 2019 can be seen in Table 1.
Table 1. Total disability products bolt product in 2019

| Month  | Production (Unit) | Total Disability (Units) | Disability Percentage (%) |
|--------|-------------------|--------------------------|---------------------------|
| January| 125               | 18                       | 14.40                     |
| February| 125              | 17                       | 13.60                     |
| March  | 130               | 17                       | 13.08                     |
| April  | 125               | 17                       | 13.60                     |
| May    | 123               | 18                       | 14.63                     |
| June   | 125               | 17                       | 13.60                     |
| July   | 125               | 16                       | 12.80                     |
| August | 127               | 18                       | 14.17                     |
| September | 125           | 17                       | 13.60                     |
| October| 130               | 17                       | 13.08                     |
| November | 124             | 18                       | 14.52                     |
| December | 125             | 17                       | 13.60                     |
| **Total** | **1509**       | **87**                    | **164.68**                |
| **Average** |                  |                           | **13.72**                 |

The number of defects in the bolt production process from January 2019 to December 2019, has an average number of defects > 13.72%, while the disability tolerance limit set by the company is + 5%. The following are some previous studies on product quality control and proposed improvements in dealing with disability problems as on some of the research above, it can be seen that the DMAIC Six sigma method is the most effective method to be used to overcome the problem of product defects. The Six Sigma method is developed and widely accepted by the industrial world because this method is able to dramatically improve quality towards a zero defect rate. So, in this research, a defect analysis will be carried out on bolt products using the six sigma approach of the DMAIC and FMEA (Failure Mode Effect and Analysis) methods to provide recommendations for improvements that should be made. [2]

2. Literature Review

2.1. Quality

Quality is a measure of how capable an item or service meets the needs of consumers according to certain standards. Certain standards may relate to time, materials, performance, reliability or quantifiable characteristics. Quality is also a conformance to specifications, and a level of conformity is a measure of quality. If the specifications do not satisfy customer needs, these specifications must be changed [3]. Quality has some difference dimensions that can be used as a basis for strategic and analyst planning for manufactured products. The following some dimensions are performance, features, conformance, reliability, durability, serviceability, aesthetics, perceived quality [4]. According to Montgomery, quality is something that is decided by the customer. Quality is based on the customer’s actual experience of the product or service, measured based on the customer’s requirements and always represents a target that moves in a competitive market [5].

2.2. Quality Control

Quality control is the use of techniques or activities to achieve, maintain and improve the quality of a product or service. The purpose of quality control is to quickly investigate the causes or shifts of the process so that an investigation of the process and corrective action can be taken before too many inappropriate units are produced. The ultimate goal of quality control is to reduce product variability [4].

2.3. Six Sigma

Six Sigma has been gaining momentum in industry; however, academics have conducted little research on this emerging phenomenon [6]. In an academic research has tried to determine which elements in Six
Sigma make it effective. Besides its role structure and focus on metrics, Six Sigma’s structured improvement procedure is seen as a novel and effective contribution to quality management. This improvement procedure is generally known under the acronym DMAIC, standing for Define, Measure, Analyze, Improve and Control [7].

2.4. Six Sigma Concept
Six Sigma is a systematic, highly disciplined, customer-centric and profit-driven organization-wide strategic business improvement initiative that is based on a rigorous process-focused and measurement driven methodology of applications [8]. If the Six Sigma concept will be established in the field of manufacturing, there are six aspects that need attention [2]:

- Identify product characteristics that satisfy customers (according to customer needs)
- Classifying all of these quality characteristics as individual CTQ (Critical-To-Quality).
- Determine whether each CTQ can be controlled through material control, work process machinery and others.
- Determine the maximum limit of tolerance for each CTQ as desired by the customer (determine the UCL and LCL value of each CTQ).
- Determine the maximum variation per CTQ each (determine the maximum standard deviation Value per each CTQ). Change the product and/or process design in such a way as to be able to achieve the Six sigma target value, which means it has an ability to process index, Cpm minimum is equal to two (Cpm ≥ 2).

2.5. DMAIC
The methodology used in the Six Sigma improvement project is DMAIC (define, measure, analyze, improve, control). The DMAIC method is widely used in Six Sigma programs at Small and medium-sized companies in the UK and provide satisfying results [9]. This traditional method is widely applied by the Six Sigma team in making improvements to reach level six sigma [10].

The data processing method used is the DMAIC method (Define, Measure, Analyze, Improve, and Control). The stages of DMAIC will be explained as follows. [11]

- Define Phase, at this stage a statement of research activities is carried out, the selection of products to be the focus of research, the description of the production process includes SIPOC diagrams, and CTQ (Critical to Quality).
- Measure Phase, at this stage product quality measurements are taken. Measurements related to product quality begin with the determination of DPMO and sigma level calculations, normality test data with the Kolmogorov-Smirnov Test, and calculation of control map limits.
- Analyze Phase, this analysis phase is carried out an analysis of the production process using a Pareto diagram, Cause and Effect Diagram analysis, then the RPN value is calculated using FMEA (Failure Mode and Effect Analysis. This analysis is carried out to reduce defective products that occur by looking at problems that occur from several factors, humans, machines, materials, work methods, the environment and measurements taken.
- Improve Phase, at this stage, targeting and alternatives will be made to improve the results of the FMEA analysis.
- Control Phase, at this stage a control effort will be made in the form of making SOPs so that the design of the improvements provided can run effectively and efficiently.

3. Research Methodology
The study was conducted at PT XYZ, where the data taken are total production and disability in the January 2019 to December 2019 period the study uses DMAIC Six Sigma. The general objective of the research is to reduce the number of defects in bolt products by identifying the causes of defects and
improvement efforts in order to produce quality products, so that it will be obtained:

- Calculating the value of Defect Per Million Opportunity (DPMO) and the level of sigma (σ)
- Getting the biggest risk of failure in the production process in the Risk Priority Number (RPN)
- Provide improvement suggestions to reduce the number of defective products

3.1. Data Collection
Data can be obtained from two main sources namely primary sources and secondary sources. Data obtained from primary sources is called primary data that is data obtained by searching / digging directly from the source by the relevant researcher. Secondary data is data that has been collected and processed by other parties so that it does not need to be explored / sought by the relevant researcher but only to quote or retrieve [12]

The data used in this study is secondary data while the data is obtained indirectly which can form file documents, archives or company records.

This study uses DMAIC in data processing which consist of:

- SIPOC Diagram
- Critical to Quality Control (CTQ)
- Control Charts
- Defect Per Million Opportunities (DPMO)
- Pareto Diagram
- Cause and Effect Diagram
- Failure Mode and Effect Analysis (FMEA)

4. Result
After all the necessary information has been collected, an analysis is carried out using DMAIC Six Sigma. The initial data collected can be seen in Table 2.

**Table 2. Percentage of defective products for the January 2019 - December 2019 period**

| Period      | Number of Defects for Each Product |
|-------------|-----------------------------------|
|             | Bolt (Unit) | Nut (Unit) |
| January     | 18          | 8          |
| February    | 17          | 8          |
| March       | 17          | 8          |
| April       | 17          | 10         |
| May         | 18          | 11         |
| June        | 17          | 8          |
| July        | 16          | 9          |
| August      | 18          | 12         |
| September   | 17          | 7          |
| October     | 17          | 10         |
| November    | 18          | 9          |
| December    | 17          | 10         |
| Number of defects | 207  | 110  |
| Number of productions | 1509 | 1394 |
| % Defect    | 13.72%      | 7.89%      |

Table 1. shows that the dominant defects are bolt products with 207 defects or 13.72% and nut products with 110 defects or 7.89%. The steps to repair the defect using DMAIC method are as follows.
- **SIPOC Diagram**
  The SIPOC diagram is used to explain the interrelationships between Supplier, Input, Process, Output, and Customer. This diagram aims to provide an overview of general information about the business processes carried out, from suppliers to customers can be seen in Table 3. [13]

| Supplier                  | Input  | Process                          | Output | Customer                      |
|---------------------------|--------|----------------------------------|--------|-------------------------------|
| Warehouse of raw material | Stainless | Metal bar cutting               | Bolt   | Finished product warehouse   |
| Warehouse of equipment    |         | Diameter formation              |        |                               |
|                           |         | Giving screws                   |        |                               |
|                           |         | Heat formation                  |        |                               |
|                           |         | Burning with fire               |        |                               |

- **Critical to Quality (CTQ)**
  Critical to Quality (CTQ) is a very important attribute to consider because it is directly related to customer needs and satisfaction. A product is categorized as a defective product, if the criteria for failure or disability have been defined in advance, can be seen in Table 4. [14]

| Critical To Quality (CTQ) | Description                                                                 |
|--------------------------|-----------------------------------------------------------------------------|
| Screw defect             | The surface of the screw is not clean, the screw is tilted which can cause a mismatch in the nut to be paired |
| Diameter defect          | The diameter of the bolt is too big or small so that it causes a mismatch in the nut to be paired |
| Bolt head defect         | The facet of the bolt head is not symmetrical or cracked so it cannot be locked by a bolt lock |

- **Control Chart**
  Determination of control limits is a requirement in the calculation of process capability. In determining the control boundary used is the map p, where the map p illustrates the part that was rejected because it does not fit the desired specifications, can be seen in Table 5.

| Subgroup | Number of Inspection (n) | Number of Defect (np) | Proportion of Defect (p) | LCL  | UCL  | Description |
|----------|-------------------------|-----------------------|--------------------------|------|------|-------------|
| 1.       | 5                       | 1                     | 0.2000                   | 0    | 0.59590 | In Control  |
| 2.       | 5                       | 0                     | 0.0000                   | 0    | 0.59590 | In Control  |
| 3.       | 5                       | 0                     | 0.0000                   | 0    | 0.59590 | In Control  |
| 4.       | 5                       | 1                     | 0.2000                   | 0    | 0.59590 | In Control  |
| 5.       | 5                       | 1                     | 0.2000                   | 0    | 0.59590 | In Control  |
| 6.       | 5                       | 1                     | 0.2000                   | 0    | 0.59590 | In Control  |
| 7.       | 5                       | 0                     | 0.0000                   | 0    | 0.59590 | In Control  |
| 8.       | 5                       | 1                     | 0.2000                   | 0    | 0.59590 | In Control  |
| 9.       | 5                       | 0                     | 0.0000                   | 0    | 0.59590 | In Control  |
| 10.      | 5                       | 1                     | 0.2000                   | 0    | 0.59590 | In Control  |
| 11.      | 5                       | 1                     | 0.2000                   | 0    | 0.59590 | In Control  |
| 12.      | 5                       | 0                     | 0.0000                   | 0    | 0.59590 | In Control  |
13. 5 0 0.0000 0 0.59590 In Control
14. 5 2 0.4000 0 0.59590 In Control
15. 5 1 0.2000 0 0.59590 In Control
16. 5 0 0.0000 0 0.59590 In Control
17. 5 1 0.2000 0 0.59590 In Control
18. 5 0 0.0000 0 0.59590 In Control
19. 5 1 0.2000 0 0.59590 In Control
20. 5 2 0.4000 0 0.59590 In Control
21. 5 1 0.2000 0 0.59590 In Control
22. 5 0 0.0000 0 0.59590 In Control
23. 5 0 0.0000 0 0.59590 In Control
24. 5 1 0.2000 0 0.59590 In Control
25. 5 1 0.2000 0 0.59590 In Control

Total 125 17 - - - -

The map of the defect product can be seen in Figure 1.

![Figure 1. Control p chart](image)

- Defect Per Million Opportunities (DPMO)
  DPMO (Defect per Million Opportunities) is a measure of failure in six sigma that shows the failure of a million opportunities, can be seen in Table 6. [5]

| Period     | Number Production (Unit) | Number of Defect (Unit) | Number of CTQ | Value of DPMO | Value of Sigma |
|------------|--------------------------|-------------------------|---------------|---------------|---------------|
| January    | 125                      | 18                      | 3             | 48.000        | 3.16          |
| February   | 125                      | 17                      | 3             | 45.333        | 3.19          |
| March      | 130                      | 17                      | 3             | 43.590        | 3.21          |
| April      | 125                      | 17                      | 3             | 45.333        | 3.19          |
| May        | 123                      | 18                      | 3             | 48.780        | 3.16          |
| June       | 125                      | 17                      | 3             | 45.333        | 3.19          |
| July       | 125                      | 16                      | 3             | 42.667        | 3.22          |
| August     | 127                      | 18                      | 3             | 47.244        | 3.17          |
| September  | 125                      | 17                      | 3             | 45.333        | 3.19          |
| October    | 130                      | 17                      | 3             | 43.590        | 3.21          |
|       | November | December | Total  |
|-------|----------|----------|--------|
| Units | 124      | 125      | 1,509  |
| Defect | 18       | 17       | 207    |
| Present | 3        | 3        | 3      |
| %     | 48.387   | 45.333   | 45.744 |
|       |          |          | 3.16   |

- **Pareto Diagram**
  Pareto is used to stratify data into groups from the largest to the smallest. By keeping in the form of bar charts, Pareto helps to identify the most common events or causes of problems. Pareto Diagrams are used to find out the types of disabilities that contribute to disability in a company [16], can be seen in Figure 2.

  ![Pareto Chart of Defect](image)

  **Figure 2.** Pareto diagram of bolt products defect

- **Cause and Effect Diagram**
  To determine possible root causes of rejection, Cause and Effect Diagram (CED) is also a very useful tool [17]. From the Pareto Diagram it can be seen that the greatest number of defects occur in screw defects with a total of 87 units. Thus an analysis of the causes of errors in these types of errors using Cause and Effect Diagrams, as shown in Figure 3. [3]
Figure 3. Cause and effect diagram (fishbone) cause of screw defect

From the Pareto Diagram it can be seen that the greatest number of defects occur in terms of defects in the head of the bolt with 68 disability units. Thus an analysis of the causes of errors on these types of errors using Cause and Effect Diagrams, as shown in Figure 4.

Figure 4. Cause and effect diagram (fishbone) cause of bolt head defect
Failure Mode Effect and Analysis (FMEA)

Failure mode and effects analysis (FMEA) only considers the impact of single failure on the system. For large and complex systems, since multiple failures of components exist, assessing multiple failure modes with all possible combinations is impractical [18]. Factors that cause disability are sorted by the highest RPN values which can be seen in Table 7.

Table 7. Sequence of process failures based on RPN value

| No. | Defects     | Causes of Defect                      | RPN |
|-----|-------------|---------------------------------------|-----|
| 1.  | Screw defect| Dirty dies, dies shift and dies are worn out | 265 |
| 2.  | Bolt head defect | Wear cutter and fan belt Break | 203 |
| 3.  | Screw defect | Engine set error                      | 164 |
| 4.  | Bolt head defect | Engine set error                      | 138 |
| 5.  | Bolt head defect | Fragile material, not according to standard | 99  |
| 6.  | Screw defect | Material not according to standard     | 86  |

Score RPN is obtained from the multiplication of three indicators namely S (severity), O (occurrence), and D (detection). Based on Table 7, the highest RPN value of 265 is obtained with the causes of failure, namely dirty dies, shifted dies and dies worn out, which is the type of failure that is the first priority for immediate improvement [19, 21].

5. Discussion

The results of the analysis show that the pareto rule used in this study is 80-20, which means 20% of product defects cause 80% problems in the production process. By using a fishbone diagram, it is found that the main causes of defect consist of 3 main factors, machines, namely humans, and materials.

6. Conclusion

The conclusions obtained based on data processing and problem solving analysis that have been carried out are as follows:

- The company's DPMO value is 45,744 and the $\sigma$ value is 3.19, which means that it is still far from the industry level in the world which reaches 6 $\sigma$ (3.4 DPMO).
- The company's highest Risk Priority Number (RPN) is 265 which is caused by a less than optimal engine condition (dirty dies, shifted dies, and worn dies).
- Proposals to improve the quality of bolt products using the Six Sigma and FMEA methods for the company, namely check the condition of the machine, make sure the dies engine is in a proper condition to operate, check the machine cutter and fan belt, increase accuracy when selecting raw materials, provide training to operators, and set SOP settings on the machine.

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