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The Application Of Six Sigma Methodhology In The Process Of Product Quality Control: A Case Study From A Steel Tower Production

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***Abstract*— This paper aims to apply the Six Sigma framework with the DMAIC methodology in the process of manufacturing quality control. The case study company is one of the companies in Indonesia that engages in the manufacturing and trading of steel plates and ready-mixed concrete for industrial construction, transportation, electricity, and communications. The goal of Six Sigma in this study was to ensure the required product quality and to avoid an increase in internal costs associated with poor product quality. In this study, Six Sigma is used to analyses the quality level of steel tower manufacturing based on the number of production and defective products from March-May 2021. The results show that the company's highest product defect rate for tower products is 2,926,829 per one million productions. Therefore, the sigma value obtained from the study shows a value of 4.256, with the criteria of 3.4 DPMO (only 3.4 defective product was found on every one million productions).**

***Keywords*— Quality, Six Sigma, Defects**

I. INTRODUCTION

In this era of modern trading, the product quality that companies offer to consumers is a fundamental aspect of competition in many markets. Quality represents a key aspect of consumers' consideration that determines whether the consumer will purchase a product. This condition has caused competition between companies in creating products that can compete in the market. One way to win this competition is to attract consumers by producing products that suit the needs and desires of consumers [1]. Therefore, companies are not only required to offer the best quality products but also required to maintain and even improve the quality of the products that they produce [2].

Improving the quality of a product is highly prioritized by the company because it can help maintain the market and increase the company's market [3]. Companies with poor product quality will find it difficult to compete with other products on the market. They will threaten profits and the future sustainability of the company's operations. In contrast, companies with good product quality will be able to compete with other products and remain in demand with profitability [4]. One of the problems that can affect product quality is the existence of damaged or defective products. Therefore, its required by companies anticipate these problems, so that product quality is maintained properly. [5]. One of the efforts the company can make in maintaining the quality of the products produced is by controlling the quality and minimizing the number of product defects within the whole production process. Minimizing defects is an effort that must be carried out continuously in terms of controlling the quality of a product [6].

One of the methods that can be used in analyzing product defects is the Six Sigma method. Six Sigma is a method used to increase product productivity and profitability. In addition, Six Sigma is an application of statistical tools that are useful for identifying, measuring, and analyzing defects in products or product waste, leading to steps to make improvements. The application of Six Sigma is expected to overcome production problems related to product defects [7]. The basic concept of Six Sigma is to improve quality to have a zero-failure rate. In other words, Six Sigma aims to minimize the occurrence of defects in a production process where the ultimate goal is to create Zero Defect conditions [8]. to achieve Zero defects is technically impossible, especially in a large and complex manufacturing project. In the application of Six Sigma, the target of defects that occur in the production process is monitored at a target of 3.4 per million opportunities called Defects per Million Opportunities (DPMO) which means that in one million units produced, there are 3.4 units with defects [9].One of the Six Sigma's main approaches in analysing defect and quality improvement is the DMAIC (Define, Measure, Analyse, Improve and Control). Sigma and DMAIC can help manufacturing organisations to achieve quality improvements in their processes and thus contribute to their search for process excellence. This methods have been previously tested and applied by several research papers to detect and analyse failure in manufacturing process by using data variability and statistical distribution [10] [11].

Therefore, this paper aims to apply the Six Sigma framework with the DMAIC methodology in the process of manufacturing quality control in steel tower production. The objective of the paper is to analyse a probability of a defect and offering a recommendation for the company to improve its quality control based on the Six Sigma Approaches.

II. Research Method

This study is conducted through a field observation at one of Indonesia's steel tower production companies. This paper analyzes the data on the number of production and defective products reports in the tower production process during March-May 2021. The data is processed using the Six Sigma method, which consists of five phases, namely DMAIC (Define, Measure, Analyze, Improve, and Control).

2.1. Define

The define stage is the first step in the quality control process using the Six Sigma method. At this stage the identification of the problem to be solved will be carried out. The problems described in this stage are in the form of Critical to Quality (CTQ). CTQ is a way of measuring products or processes where performance standards or specification limits must be in accordance with customer satisfaction [1].

2.2. Measure

The "Measure" phase began with preparing detailed process maps and data collection, followed by analysing the initial state and conducting a process capability analysis of the discharge process. In this step, P-Chart is used to monitor the proportion of nonconforming units in a the production report sample, where the sample proportion nonconforming is defined as the ratio of the number of nonconforming units to the sample size [1]. This diagram is used to evaluate whether a production process is under statistical quality control or not so that it can solve problems and produce quality improvements. [13]. The formulation of the diagram is arranged as follow:

- Sample size proportioning
- The proportions of the non-conforming sample

$$p = \frac{np}{n} \qquad (1)$$

Where *p* denotes the total number of defectives (np) or non-conforming units divided by the total number of items sampled (n).

- Central Limit (CL) for variation in the sampling data

$$CL = \frac{\Sigma np}{\Sigma n} \qquad (2)$$

- The Upper Central Limit (UCL)

$$UCL = p+3\sqrt{\frac{p\,(1\text{-}p)}{n}} \qquad (3)$$

- The Lower Central Limit (LCL)

$$LCL = p+3\sqrt{\frac{p\,(1\text{-}p)}{n}} \qquad (4)$$

- Measuring the process capability based on the defects per opportunity (DPO). DPO is a failure measurement notation that shows the number of defects per opportunity. The DPO is calculated by using the following formula:

$$DPO = \frac{\text{Number of Deffect Per production}}{\text{Total Production} \times \text{CTQ}} \qquad (5)$$

- Measuring the *Defect per Million Opportunities* (DPMO). DPMO defines the number of defects in the manufacturing process in one permilion opportunines. DPMO is process by using stated formula:

$$DPMO = DPO \text{ x } 1{,}000{,}000 \qquad (5)$$

- The Calculation of Sigma Levels. The Sigma level is determined by converting the DPMO according to the table below:

TABLE I SIGMA LEVEL VALUE

Sigma	***Parts per Million***
6	3.4 *defects*
5	233 *defects*
4	6.210 *defects*
3	66.807 *defects*
2	308.537 *defects*
1	690.00 *defects*

2.3. Analyze

Analyze is the third operational step in quality control using the Six Sigma method. Where, the factors that cause defects in the products were identified and analyzed. In this phase it is needed to define process capability, clarify the goals based on real data gained in the measure phase and start root cause analysis which has impact on process variability. By calculating process capability which is defined as "sigma" of the process, ability of the process to meet customers' requirement is measured. the step to identify the factors that cause disability is done using a cause-and-effect diagram, commonly known as a fishbone diagram. The cause-and-effect diagram shows the relationship between the problems encountered, their causes, and the factors that influence them. This diagram is used to facilitate product design and prevent defects, as well as analyze and determine the most influential causal factors in the occurrence of defects. [14].

2.4. Improve

Improve is the fourth operational step to control quality using the Six Sigma method. If the causes of quality problems have been identified, then a solution is designed to reduce and eliminate the causes that encourage the appearance of defects in the product. The designed solution can be in the form of recommendations to fix discrepancies in production process practices.

2.5. Control

Control is the last operational step in quality control efforts using the Six Sigma method. At this stage, the results of quality control efforts are documented to serve as work guidelines to prevent the same problem from occurring or even recurring. The control stage mainly describes if changes implemented at the improve stage are sufficient and continuous by verifying the quality of the improved process. It also controls the future state of the process to minimize deviation from the objectives and ensure that the correction is implemented before it would have bad influence on the result in the process.

III. RESEARCH AND DISSCUSSION

3.1. Define

In these stages, the “define” process is conducted by examining the production process report of the case study company. The define process aims to troubleshoot the percentage or ratio of defect per unit of production. Therefore, the following table reports the number of production and the number of defective products in the steel tower production process during March-May 2021.

TABLE II DEFECT OCCURRENCE PERPRODUCTION

Period (Week)	*Total Production (unit)*	*Number of Defects (unit)*	*Percentage (%)*
Week I	562	6	1.068
Week II	558	5	0.896
Week III	663	6	0.905
Week IV	1832	8	0.437
Week V	1767	7	0.396
Week VI	2493	10	0.401
Week VII	815	6	0.736
Week VIII	1066	7	0.657
Week IX	1285	6	0.467
Week X	2381	9	0.378
Week XI	205	1	0.488
Week XII	1016	7	0.689
Week XIII	963	7	0.727

3.2. Measure

The measurement process in this paper is carried based on three mounts observation on the production data. the measurement aims to identify each defect occurring during the product control process. More than 1,100 of annealed coils were subjected to control. Two basic types of defects were identified by Pareto analysis: mechanical damage and sticking of the coil.

TABLE III P-CHART VALUE

Period (Week)	*Total production (pcs)*	*Defects (pcs)*	*Percentage (%)*	*P*	*CL*	*UCL*	*LCL*
Week I	562	6	1.068	0.011	0.006	0.024	-0.002
Week II	558	5	0.896	0.009	0.006	0.021	-0.003
Week III	663	6	0.905	0.009	0.006	0.020	-0.002
Week IV	1832	8	0.437	0.004	0.006	0.009	0.000

Week V	1767	7	0.396	0.004	0.006	0.008	-0.001
Week VI	2493	10	0.401	0.004	0.006	0.008	0.000
Week VII	815	6	0.736	0.007	0.006	0.016	-0.002
Week VIII	1066	7	0.657	0.007	0.006	0.014	-0.001
Week IX	1285	6	0.467	0.005	0.006	0.010	-0.001
Week X	2381	9	0.378	0.004	0.006	0.008	0.000
Week XI	205	3	1,463	0.015	0.007	0.040	-0.011
Week XII	1016	7	0.689	0.007	0.006	0.015	-0.001
Week XIII	963	7	0.727	0.007	0.006	0.015	-0.001

To understand the accuracy and predictability of the proportion of nonconforming units in a sample, this paper used the P-Chart process to measure the ratio of the defect to the total of production unit from the define phases. Fig 1. Illustrates the proposed P-char of the defect in the case study company.

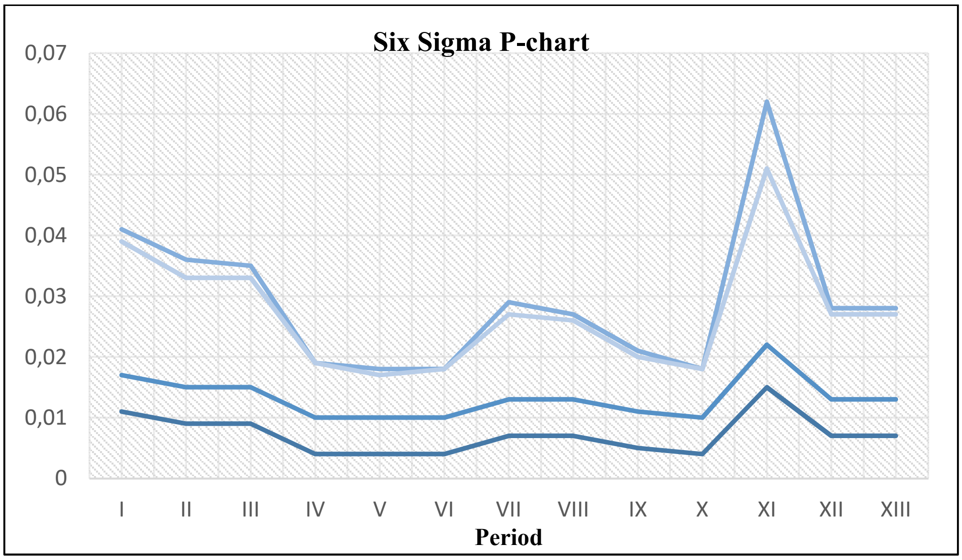

Fig 1. P-chart for the product defect occurrence.

Based on figure I above, the average value of the proportion of disability (p) is close to the central line or Central Limit (CL), and no data appears outside the upper control limits (UCL) and the lower control limits (LCL). Therefore, the quality measured is considered normal and requires no intervention in the relevant process. Furthermore, to observe the capability of the process to meet the specification limit of the production process. Therefore, this paper used the process capability measurement to analyze the data. Table IV explain the result of process capability measurement of the case study company.

TABLE IV PROCESS CAPABILITY MEASUREMENT

Period	*Total production per week (pcs)*	*Defect per production*	*Percentage (%)*	*CTQ*	*DPO*	*DPMO*	*Sigma*
Week I	562	6	1.068	5	0.002	2135.231	4.357
Week II	558	5	0.896	5	0.002	1792.115	4.413
Week III	663	6	0.905	5	0.002	1809.955	4.410
Week IV	1832	8	0.437	5	0.001	873.362	4.630
Week V	1767	7	0.396	5	0.001	792,303	4.659
Week VI	2493	10	0.401	5	0.001	802.246	4.655
Week VII	815	6	0.736	5	0.001	1472.393	4.473
Week VIII	1066	7	0.657	5	0.001	1313.321	4.508
Week IX	1285	6	0.467	5	0.001	933.852	4.611
Week X	2381	9	0.378	5	0.001	755.985	4.672
Week XI	205	3	1,463	5	0.003	2926.829	4.256
Week XII	1016	7	0.689	5	0.001	1377.953	4.494
Week XIII	963	7	0.727	5	0.001	1453.790	4.477

Based on the results of the data recapitulation on the capability values in the table above, it can be seen that the DPMO level and Sigma level show an inconsistent value. The values obtained indicates a vast variation between the sigma and DPMO levels. Therefore, the production process requires more process n to obtain a decreased DPMO pattern, and the Sigma level pattern has increased over time [16].

3.3. Analyze

There are several types of defects identified in the production process of the steel tower production. Defects such as 1) Dross (A thin layer of re-solidified metal that can form along the sides or bottom of the kerf, 2) unfitted material to the drawing specification, 3) distance between hole in each drawing, 4) The dimensional thickness that does not match specifications. Therefore, fishbone diagram is used analyses the situational cause of the defect within the production process. In this paper, the fishbone diagram helped to identify the possible factors causing the failure of production. The result of fishbone diagram can be seen in Figure II. Furthermore, the fishbone diagram, this paper summarizes several root causes of the occurrence of the defect in the quality control process based on four aspects. The defects that occur in the elbow tower product are caused by four aspects, namely man, machine, methods, and the material that was used in the process. Based on the human aspect, it can be seen that there are two main causes that may have caused the product defects.

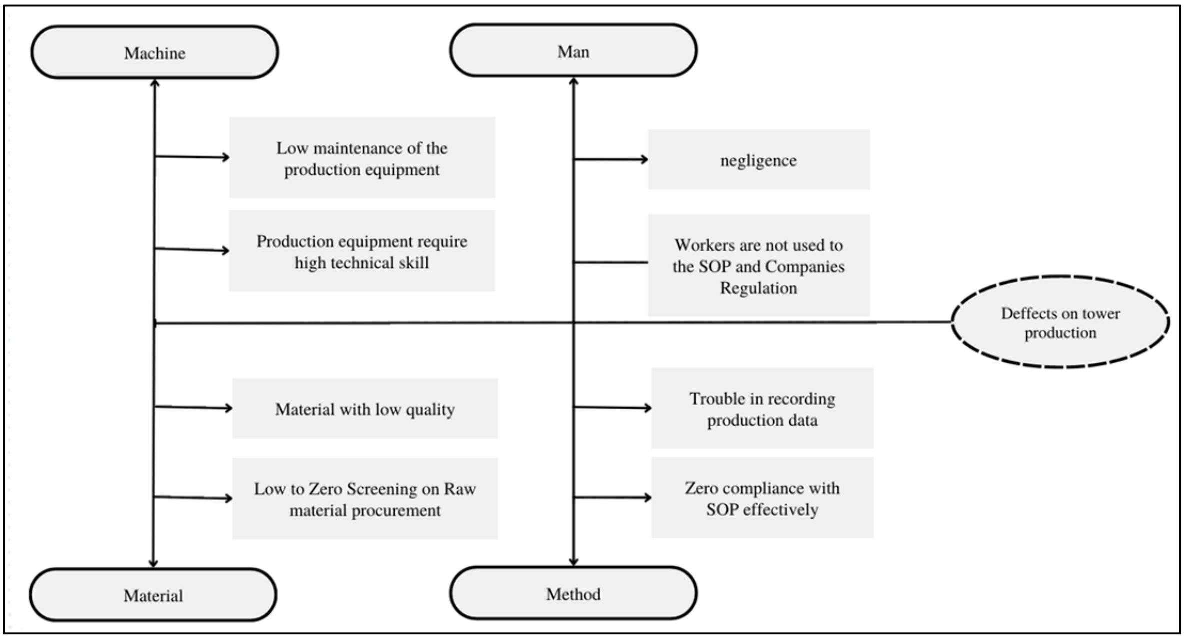

Fig 2. Cause and effect diagram on the quality control process.

The first is due to the negligence of human resources at work, which is caused by workers who are not familiar with the production SOPs (Standard Operating Procedures), which are based on helper workers who are used non-permanently. The second factor is the frequent miscommunication due to the presence of two work shifts at the company. Based on the machinery aspect, it can be seen that product defects are caused by machine factors that are difficult to control, such as the machine working slower when it has been used for too long. The problem is due to the need for more maintenance done to the machine. Based on the aspect of raw materials, it can be seen that the quality of raw materials causes product defects not according to standards. This occurs because the material inspection needs to be more detailed, where the inspection is carried out thoroughly. Furthermore, the aspect of method explains to cause of defect on the tower production. The first is because the number of defective products is not recorded thoroughly, and there are no detailed records of inspections carried out every day. The second factor is the lack of following established procedures.

3.4. Analyze

The following solution that this paper recommended to reduce the level of defects in tower production, the recommendations in study were based on previous study from several literatures. The recommended of the paper is presented as follow:

TABLE V RECOMMENDATION

No	***Cause Factors***	***Root Cause***	***Recommendation***	***Subhead***
1	Man	Frequent rotation in workplace station	Enforcing a strict standard operation procedure (SOP) for each assignment	[6]
		Multiple work shift that may cause confusion to the workload	Good communication flow and data recording is needed to ensure a smooth production process each assigned shift.	[1]
2	Machine	Low maintenance of production equipment	Enforcing an extra supervision of all parts of production equipment and perform machinery maintenance on a regular	[16]

No	*Cause Factors*	*Root Cause*	*Recommendation*	*Subhead*
			basis	
3	Material	Materials are not thoroughly inspected	Improving the quality standards of materials received and increasing the accuracy of each material inspection	[16]
			Conduct material inspections using certain sampling methods to make them more accurate.	[1]
4	Method	No effective record on the production process	Conduct a detailed records of products that are inspected every day.	[16]
		Low compliance on the established procedures	The supervisor directs the operator to understand the existing procedures before carrying out the production process	[15], [16]

3.5. Control

This paper utilizes the DMAIC concept of the Six Sigma methodology as an attempt to analyze the quality of the product of a steel tower production company in Indonesia. The application of the DMAIC tool improved the quality of the annealing operation in five essential phases. During these phases, the process was defined in detail. The data from the process were gathered, the root cause of the defects was analyzed. and the recommendation were proposed to improve the details that may cause the product's defect. The results achieved by the DMAIC tool of the Six Sigma methodology have confirmed that the company has a proper quality control system. Where can be seen that the number of product defects produced is fairly low, with a sigma value of 4 sigma's which is getting closer to the value of 6-sigmas. However, there are several recommendations for supervision that the company can do to continue to monitor the production process so that the quality control system at the case study company will get better in the future. First, the company can carry out strict supervision in scheduling regular machine maintenance so that it runs consistently. Secondly, enforcing intensive inspections of supervisors/supervisors. Thirdly, evaluate production processes regularly every month, and superiors provide directions to operators. And the last recommendation was to understand the existing procedures before production.

IV. Conclusion

The case study company represented in this paper is a company engaged in the manufacturing and trading steel tower in Indonesia. Based on data on the number of production reports and the number of defective products for March-May 2021, data processing was carried out using the Six Sigma method, which shows the highest value for the company's defect rate for elbow tower products is 2.926.829 DPMO. The value means that as many as 2.926.829 defective products are produced in one million productions. The sigma value obtained is 4.256 sigma. This value is considered good because it is close to the 6-sigma value, which has a 3.4 DPMO criterion (only 3.4 defective products are produced for every one million productions). The 4-sigma value is good considering that this company is a company on a growing scale. The results show that four aspects can potentially cause defective products. The four aspects include machines, people, methods, and materials. The causes of product defects are identified using a Cause-Effect Diagram (Fishbone). The most influencing aspect here is the human. Most product defects produced are caused by helper workers who are not permanent, so several products differ from the pictures and specifications. Several suggestions for improvement are given to reduce the level of product defects so that the quality control system at PT XYZ is improving. Some of these improvements include using the same helper worker every time a new SPK (Work Order) is issued so that the helper is familiar with SOP production, performs extra supervision of all machine parts and performs machine servicing regularly.

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