Plastic Injection Quality Controlling Using the Lean Six Sigma and FMEA Method

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Abstract. PT. Yogya Presisi Teknikatama Industri (PT. YPTI) is a mold, precision part, and plastic injection maker company. One of the obstacles faced by the company is the high level of nonconformity on its production results. The waste on production process can be identified and classified into four types, i.e.: a). during the process of injection molding machines, b). finishing and cutting processes, c). quality control process and d). the packaging process. The objectives of this research are minimizing the defective goods and reducing the waste using Lean Six Sigma and FMEA approaches, especially for Bush product. From the analysis result, defective types on Bush product can be classified into bubble, speckle, short shoot, sunken, sink mark, over-cut, flashing, and discolor. Based on the attributes data on Bush product, the DPMO score is 988.42 or the sigma level is 4.6. While the DPMO score on the variable data on each dimension i.e.: a). Slit width on the bottom side has DPMO score of 30119 (sigma level 3.37), b). Diameter of the circle on the top side has DPMO score of 392294 (sigma level 1.77), c). Product thickness on the top side has DPMO score of 70474 (sigma level 2.97), d). Product height has DPMO score of 82107 (sigma level 2.89), and f). Diameter of the circle on the bottom side has DPMO score of 24448 (sigma level 3.47). The highest RPN score on the dominant types of product defects which needs improvement are the defective goods of bubble type has RPN score of 729, flashing and the molten material out on the heating channel has RPN score of 384, over cutting has RPN score of 324 and sink mark has RPN score of 270. The recommendations for improvement that can be given from this research are making checklist for maintenance and production monitoring, enhancing work supervision and inspection, as well as improving the environment and work stations.

1. Introduction

Development of manufacturing industries in Indonesia has increased by 6.8% in the last three years. For more than twenty years, the role of manufacturing industries to the economy of Indonesia has improved substantially [1]. In global market competition, products with good quality are absolutely required. Quality can be in the form of service to customers. To improve the products’ quality, companies should recognize their processing capability. It is intended to determine the extent of the company’s products to meet the customers’ needs and furthermore it can be used as a basis for controlling and improving the quality of the product characteristics [2].

The key factor that will bring the manufacturing industries to success is quality. The quality of a product is defined as the degree/level where the product or service is able to satisfy the desires of
customers (fitness for use). The quality of a product is its ability to provide appropriate performance or results, even in excess of what customers want [3]. Quality is the basic factor of the customers to get the product [4]. To maintain the consistency of the products produced and in accordance with the demands of the market, it is necessary to do a quality control on the production activities. [5] said that quality consists of some special products which can satisfy customers’ need because using the product. [6] used the lean six sigma method to reduce rejected cover powder box and powder box products. [7] used the method to give improvisation at production line considering the environmental factor, while [8] gave internal customer satisfaction criteria beside cost and time in implantation the lean sigma.

PT. Yogya Presisi Teknikatama Industri (PT. YPTI) is one of the companies engaged in the service of making mold of a product, precision parts for the needs of industrial machines, as well as plastic injection. One of the products produced in the plastic injection division is Bush. It has some defects and there are also wastes such as short shoot, spots, sink marks, bubbles, over-cut, under-cut and scratch. As for the waste during the production process, there are material that comes out of the hopper dryer, reparation of broken machines and material rework results using crusher machines scattered around the production area.

Many types of defects and the waste that occurs during production process will cause more costs for companies. This research offers improvisation of quality control system using integration of the Lean Six Sigma and Failure Mode and Effect Analysis (FMEA) methods; not only for the products, but also for the production process. Therefore, by using the Lean approach it is expected to know how much the waste will increase the production costs and by using the Six Sigma concept, the company can improve the product quality level and minimize the defective product level. Improvement using the FMEA is expected to identify the root causes of defective products as well as priority improvement on the dominant factor which causes the defective products from the highest RPN score.

2. Literature Review

2.1 Quality
[9] interpreted quality in expanded definition, in which it is a dynamic condition related to products, services, people, processes, and environments that meet or exceed expectations. [10] explained that a product quality is an overall evaluation to customer for improved the performance of goods or services. Product quality is an important aspect to be noticed by customers before they decide to buy a product. The conventional definition of quality is usually directly describe the characteristics of a product such as performance, reliability, easy to use, aesthetics, etc.; while the definition of strategic illustrates that quality is everything that is able to meet the desires or needs of the customers [11].

2.2 Quality Control
[12] described Quality Control as a material control activity which aims to determine the actual material to comply with the conditions established during planning. Therefore, the quality control is an activity to maintain the standardization of the quality of a product or material from the process of preparation, storage, to production point of consumption by the consumer. There are four steps of quality control in general, i.e.:
- Setting the Standards
  It is to determine the cost of quality standards, quality standards of performance, quality standards of security and quality standards.
- Assessing Suitability
  It is to compare the problem of the products or services offered on the standards that have been set.
- Acting if necessary
  It is by correcting the problem and its cause through the factors that include marketing, design, engineering, production and maintenance that affect customer satisfaction.
• Planning for improvement
  It is by developing a continuous effort to improve the standards of cost, achievement, security, and reliability.

2.3 Six Sigma
Six Sigma is a quality improvement vision towards the target of 3.4 per million opportunities failures (DPMO) for each transaction of products (goods and services), vigorous effort towards perfection (zero defects) [13]. Six Sigma is a technique that allows objective assessment of process performance. The Sigma-metric quantifies the performance (and thus the risk) of an analytical testing process. The method decision chart is a visual tool that differentiates Sigma performance. The operating specifications chart is a visual tool that identifies the quality control (QC) required by a test, based on Sigma performance [14]. Six Sigma QC design tools can enhance FMEA, the risk assessment process, and design of quality. There are five basic stages in using the Six Sigma strategy, i.e. Define, Measure, Analyze, Improve, Control (DMAIC), in which the stages is continuous or creating a Six Sigma quality improvement cycle. The DMAIC can be described as follow:

![Figure 1. The DMAIC Cycle [15]](figure)

2.3.1. Define
It is an early operational stage in Six Sigma quality improvement program. In this stage, there are two important things to do, i.e. defining the core process of the company and defining the customers’ needs specifically.

2.3.2. Measure
In the second stage of the Six Sigma quality improvement program, there are three main things [13], i.e. determining the key quality characteristics, developing the data collection plan, and measuring the performance baseline.

2.3.3. Analyze
In the third stage of the Six Sigma quality improvement program, there are three important things to do, i.e. determining the process stability and capability, determining the performance target of the key quality characteristics, and identifying the sources and root causes of the quality problems.

2.3.4. Improve
After identifying the sources and the root causes of the quality problems, we need to determine the action plan for the Six Sigma quality improvement. Basically the action plans will describe the allocation of resources and priorities and/or the alternatives made in the implementation of the plan.

2.3.5. Control
As a part of the Six Sigma approach, it needs controlling to ensure that the desired results are in the process of attainment. Results of the improve phase should be applied within a certain time to be able to see the effect on the quality of the product produced. At this stage the results of quality improvement are documented and disseminated, successful best practices in improving the process are standardized and disseminated, procedures are documented and used as working guideline standards, as well as the ownership or responsibility is transferred from the Six Sigma team to the owner or person in charge of the process.

2.4 Lean
Lean is a systematic methodology to reduce complexity and expedite the process by identifying the source of the waste in the process, because the waste can lead to the breakdown of the production flow. The concept of Lean is also defined as a systemic approach and systematic to identify and eliminate the waste or on-value-adding activities through continuous improvement radically by flowing the product (material, work-in-process, and output) and information using the pull system from internal and external customers for the pursuit of excellence and perfection [16].

2.5 Failure Mode and Effect Analysis (FMEA)
Another six sigma tools that are often used to identify the sources and root causes of the problem is the quality of FMEA. FMEA is a structured procedure to identify and prevent as much as possible failure modes. A failure mode is everything included in defects or failures in the design, condition beyond the limits established specifications or changes in the product that causes the disruption of the function of the product.

3. Research Methods
This research used quantitative methods, which can be interpreted as a research method based on the philosophy of positivism, used to examine the population or a particular sample, the sampling technique is generally done at random. Data are collected by using the research instruments, the analysis of quantitative data or statistics with the aim to test the hypothesis that has been established [17]. Field studies were conducted in this study including observation, interviews and identification to reveal the facts that there are deeper so as to provide solutions to existing problems.

4. Data Processing and Discussion
4.1 Stage 1: Define
In this stage, we did an identification of waste in the production process as well as identified the value added and non-value added activities in the company. The production process for Bush product in PT. YPTI was done in the plastic injection division which uses the SIPOC (Supplier, Input, Process, Output, and Customer) diagram flow system can be illustrated as follow:
Figure 2. The SIPOC Diagram

And here is the technical figure for Bush product:

![Technical Figure](image)

Figure 3. Dimension Specification of Bush product

Description of the product specifications are as follows:
The types of waste in the Bush production process in PT.YPTI can be identified and classified into four processes, i.e. during the process of injection molding machines, finishing and cutting processes, quality control process and the packaging process. Besides, we found that there are several value added and non-value added activities for the company. Some of the non-value added activities will have a direct impact on the production process. For example the process of cutting products will be stopped when the operator fix the pedestal where the cuts and look for the products that fall. Activities to reprocess the defective products (rework) also add to production costs and make the production process to be longer. Efforts to prevent the recurrence of the non-value added activities can be done by increasing the discipline of production operators, setting the machine according to the procedures and minimizing the occurrence of defects in the product. Thus the waste and non-value added activities should receive serious attention from companies and carried out improvement efforts.

4.2 Stage 2: Measure

In this stage, we did measurement and deeper analysis of the defect types of Bush product, grouping the most potential defect types which affect the product quality and analyzing the stability and capability of the production process.

4.2.1 Critical to Quality (CTQ) Analysis

Based on the calculation result, we found the defective amounts and the percentage of each defect type, i.e. Bubble was 2,460 pcs (47.19%), Speckle was 1,521 pcs (29.18%), Short Shoot was 1,112 pcs (21.33%), Sink Mark was 48 pieces (0.92%), Discolor was 30 pcs (0.58%), Sunken was 20 pcs (0.38%), Flashing was 16 pcs (0.31%) and Over-cut was 6 pcs (0.12%).
Based on the above figure, there are 3 out of 8 defect types which incurred the most on Bush production in 2014, i.e. Bubble, Short Shoot and Speckle; so those three will be considered as the Critical to Quality.

4.2.2. Analysis of Process Level and Output

Based on the total number of defects that is used as the attribute for the calculation of the whole products in 2014, the DPMO score is 988.42 or 4.6 sigma level, which means that the company is still producing defective products for 5213 pieces per one million products. For 2014 the overall process can be considered as quite competitive and are at the USA’s average industry. As for the variable data, the DPMO score is quite high and sigma level is still far from the target. The variable of slit width on the bottom side has DPMO score of 30119 (3.37 sigma level), diameter of the circle on the top side has DPMO score of 392.294 DPMO (1.77 sigma level), the product thickness on the top side has DPMO value 70 474 (2.97 sigma level), high the product has DPMO score of 82107 (2.89 sigma level), product thickness on the bottom side has DPMO score of 24448 (3.47 sigma level) and the diameter of the circle on the bottom side has DPMO score of 24448 (sigma level 3.47). Based on the results of the data processing, the DPMO score of the Bush products’ variable data is quite high and the sigma level is still far from the target, which is only 3.4 sigma. In other words, it can be said that the capability score of the process is still at the average level of Indonesia and less competitive, while at the present time many World Class companies have the process capability on quality control at the rate of 5-6 sigma, so they only produces the probability of failure per one million opportunities DPMO below 100.

4.3 Stage 3: Analyze

4.3.1. Process Stability Analysis

At this stage, we analyzed the process stability which was done towards the attribute data, i.e. the number of defects produced in January to December 2014.

![Figure 6. The Map Graphic of Bush Production Process Controlling](image)

Based on the figure above, the controlling of Bush production process in 2014 is not stable. This is shown in the chart that in the 1, 2, 4, 5, 6, 7, 8, 9, 10, and 12 periods there were of control in the production process. In other words, there was proportion of defective products which passed the upper and lower limit control. Therefore, it needs some improvements and efforts to reduce losses due to the defective products.

4.3.2. Process Capability Analysis

Based on the results of data processing and capability analysis for the entire product process of Bush variable data, the index score of $C_{pm}$ and $C_{pmk}$ is less than 1 or $C_{pm}$ and $C_{pmk} < 1$. It shows that the whole process were not able to meet the specifications set by the customers and not competitive to
compete in the global market. Therefore it needs some improvement efforts to enhance the process capability by reducing and minimizing variation in each variable and conducting continuous improvement program in order to compete in the global market.

4.3.3. **Source and Root Cause of Defective Products Analysis**
The defective on Bush products are generally caused by several factors such as human, material, machines, methods and work environment. The main factor of the defective goods in PT. YPTI is that the machine’s engine is old and the result of reconditioning. As for the human factor is because the production operators lack of discipline and fatigue due to positions and less ergonomic workplace. The material also became one of the causes of speckle defects, where the results of rework material mixed with another color material in the hopper dryer and there are still other waste materials, causing speckle defects in the product. Methods and the work environment factors were caused by operators who do not follow the Standard Operating Procedure of employment and rework processes. As for the environmental factors were caused by the noise generated from the crusher machine’s engine sound during the rework process, the position of the air conditioners which are too far from the operators and the less clean workplace.

4.4 **Stage 4: Improve**

4.4.1. **Improvement Analysis Using FMEA**
From the calculation of FMEA, the highest RPN score on the dominant types of product defects which need improvement are the defective goods of bubble type with RPN score of 729, flashing and the molten material out on the heating channel with RPN score of 384, over cutting with RPN score of 324 and sink mark with RPN score of 270. Improvement recommendations to prevent recurrence of defects in the bush products are:

- **For bubble defect**:
  - Make sure the material passes through the proper drying.
  - Raise screw back pressure during plasticizing process to force the gas out of the cylinder.
  - Fix the gas ventilation system in the mold so that the gas is not trapped in the product.
  - Lower the speed of injection to allow time for the gas to come out through the ventilation system.
- **For the molten material out on the heating channel problems**:
  - Make sure the barrel is precise/fit the mold hole.
  - Clean the mold so the holes are not clogged and the material can flow smoothly into the mold.
- **For the flashing and sink mark defect**:
  - If the problem refers to the quality of the material, it can be replaced with a material with a grade which has a better flow rate and it can also reduce the temperature of the plastic.
  - If the problem refers to the wear of the mold, the mold can be repaired or replaced with a better mold.
  - Reduce product time cycle because it can cause flashing on the product if used for too long.
- **For over-cut defect**
  - Improving the tools and production operator work station
  - Increase the rigor and discipline operator
  - Providing working facilities such as air conditioner or replace seats and a more ergonomic work desk.

4.4.2. **Process Flow Analysis**
The activities which have been identified and can be eliminated in the production process of a bush that is contained in the finishing and cutting process, the quality control process and the packaging process. Proposed improvement and simplification of the flow of the activities provided during the
process of finishing and cutting is to eliminate the activity of inserting the stem of products bush into
the scoop before it is poured into the engine crusher, further improvement is to eliminate the activity
of collecting and placing the product on the table of the operator before it packaged into size plastic
1kg/100pcs because such activity causes the table as a cutting area becomes narrower. Improvement of
the process flow given during the process of quality control and packaging is to eliminate the activity,
returns the defective product to the production station, perform the rework and re-count the number of
products that have been packed into a plastic measuring 1 kg/100pcs. Those activities can be a waste
for the company. Losses that could be caused by waste is that it can lead to a production process
becomes longer, higher production costs and decreased worker productivity.

4.5 Stage 5: Control
This objective of this stage is to ensure that the improved conditions can be sustainable and maintained
in the future. Some surveillance activities and the proposed improvements that can be made are as
follows:
  • Creating maintenance checklist sheet and monitoring the production process so that it could be a
    reference at the time of production in the future. The next control is to perform maintenance and
    checking the machine periodically intensively by Setter in order to minimize product defects
    caused by the machine factor.
  • Improve supervision and work inspection. This control can be done by increasing oversight by the
    leader of the discipline of operators in order to minimize the production of defective products
    caused by human factors. Assessment of performance and provide training to the work force can
    be used as an attempt to improve the skills and abilities of workers, where the ultimate goal is to
    increase worker productivity.
  • Fixing the environment and work stations. This form of control can be done by reducing the level
    of noise generated by the crusher machine’s engine sound during the rework process and close the
    doors and installing a silencer in the Crusher room. Other controls can be done by improving the
    operator work station such as by replacing the chairs and tables more ergonomic so that workers
    can work safely, comfortably and can prevent the occurrence of occupational diseases.

5. Conclusion and Recommendation

5.1 Conclusion
Based on the results of the data collection and processing as well as the analysis that has been
explained above, it can be concluded that:
  • The types of waste in the Bush production process in PT. YPTI can be identified and classified
    into four processes, i.e. during the process of injection molding machines, finishing and cutting
    processes, quality control process and the packaging process. As for the types of defects found on
    the Bush product are bubble, speckle, short shoot, sunken, sink mark, over-cut, flashing and
discolor.
  • Based on the total number of defects that is used as the attribute for the calculation of the whole
    products in 2014, the DPMO score is 988.42 or 4.6 sigma level, which means that the company is
    still producing defective products for 5213 pieces per one million products. For 2014 the overall
    process can be considered as quite competitive and are at the USA’s average industry. While the
    results of the data processing from the Bush products’ variable data, the DPMO score is quite high
    and the sigma level is still far from the target, which is only 3.4 sigma. In other words, it can be
    said that the capability score of the process is still at the average level of Indonesia and less
    competitive.
  • The highest RPN score on the dominant types of product defects which needs improvement are the
    defective goods of bubble type with RPN score of 729, flashing and the molten material out on the
    heating channel with RPN score of 384, over cutting with RPN score of 324 and sink mark with
    RPN score of 270.
5.2 Recommendation
The following are the recommendation from the researchers for the improvement of PT. YPTI:
• Creating maintenance checklist sheet and monitoring the production process.
• Enhancing the work supervision and inspection.
• Improving the environment and work stations.

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