Quality control of bottled tea packaging using the Statistical Quality Control (SQC) and the Failure Mode and Effect Analysis (FMEA)

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Abstract. The packaging is a container used for preventing or minimising the damage of products. Company X is one of the companies engaged in beverage packaging, and one of its larger product is bottled tea. The primary packaging of the tea is a semi-finished PET bottle. Its small and light shape is beneficial to reduce transportation costs. Quality control is carried out so that the products are following predetermined standards and the consumer's requirements. This research aimed to identify the potential risk of the bottled tea packaging and to reduce the defect to increase the productivity of the company using statistical quality control (SQC) and the analysis of failure modes and effects (FMEA). SQC results showed that the highest number of damage occurred in February 2019 at 3.95%. The results of the risk analysis using FMEA showed that defective preform was the main risk that needed to be controlled. This risk had a Risk Priority Number (RPN) of 294, caused by supplier errors.

1. Introduction

Tea is one of the non-alcoholic drinks consumed in large quantities in Indonesia. Tea is made from processed young shoots of Camelia sinensis. The benefits of drinking tea are providing a fresh taste and restore body health. Regular tea consumption does have adverse effects [1]. In the beverage company production system, the packaging is essential. Direct packaging is related to the quality of a beverage product manufactured. Packaging maintains the quality of the beverage from contact with the surrounding environment so that contamination can be prevented. The quality control process in packaging is something that must be carried out as a form of industry commitment to maintain the quality of its products. Packaging becomes vital because it is used to protect the products. Also, packaging can be considered as the companies purpose to present products that are more attractive in terms of shape and colour. The quality of packaging can be observed from the packaging material, the form of packaging and the labelling [2]. Company X produced bottle oolong tea drinks as the basic ingredient. Its primary packaging is made from plastic and cardboard as the secondary packaging.

Statistics Quality Control (SQC), as a production-quality control tool, can help companies maintaining control of the ingredient ingredients' production processes and final products [3]. Quality control is needed to meet standards and the consumer’s desires. Two methods can be done by SQC,
namely Pareto charts and fishbone diagrams to see the number of defective products and analysing the impacts of these product defects. Meanwhile, the FMEA method is employed to identify the stages of the process that caused the defects [4]. This research aims to reduce the occurring defects.

2. Materials and Method
This research was conducted in company X. The data processing was carried out at the Laboratory of Computing and Systems Analysis of the Department of Agroindustrial Technology, Faculty of Agricultural Technology, Universitas Brawijaya. The methods used in this study were the Statistical Quality Control (SQC) method and the Failure Mode and Effect Analysis (FMEA) method. The research material was bottled tea primary packaging.

The data processing was performed after the required data was collected, and then the data was processed using the Pareto chart, fishbone diagram and FMEA method. Pareto chart and fishbone diagram are part of Statistical Quality Control. The Pareto chart was utilized to determine the number of defective products, and the fishbone diagram was used to analyze the causes of product defects. Then, it was continued with the FMEA method to find the most critical risk in the production process to obtain the solutions to these problems immediately. The steps are as follows:

1. Conducting surveys and interviews in Company X.
   Preliminary surveys and interviews were aimed to find out the actual condition of the company that can be used in the formulation of problems that exist in the company and can provide exact direction steps taken next by researchers.

2. Developing a P control chart
   Data related to quality control of tea packaging is taken from several tea packaging processes carried out by Company X which are influential attributes to the P control chart for product packaging data that is not following company standards. The use of P control chart for defective packaging products with Equation 1. If the calculation results show that the process is not under control, the process will be improved.

   \[ p = \frac{\text{Defect}}{\text{Production}}, \quad \text{Sp} = \sqrt{\frac{p(1-p)}{n}} \]  

3. Developing a pareto chart
   The Pareto chart shows the frequency distribution of attribute data arranged by category. The chart is a bar chart showing problems based on the order of the number of events from the number of problems that occurred the most until the least occurred [5]. In this study, it is used to find out the damage data of tea products from industry X, and the defects that often occur in the tea packaging process.

4. Developing a fishbone diagram
   A Fishbone diagram is one method to improve quality [6]. The steps taken are to determine the problem that will be observed in the diagram (preform defects, foreign material, cap damage, conveyor problems). The determination of the problem in the diagram is determined by the production manager because of his expertise in assessing the level of problems that exist in the process.

5. Failure Mode Effect Analysis (FMEA)
   The steps in making an FMEA table are to write down all the main steps of the tea packaging process carried out by industry X. In the first column, the researcher makes a list of potential failures (failure modes) for each step of the packaging process, makes a list of the effects of failure modes in the previous list, then determines rating on the value of S (severity), O (occurrence), and D (detection). The final step is to multiply the numbers in the 'S' (severity), 'O' (occurrence) and 'D' (detection) columns then the results are entered in the 'RPN' (risk priority number) column [7]. The highest RPN value gets the highest priority scale for improvement. The following table will present a table of S (severity), O (occurrence) and D (detection) values.
3. Results and Discussion

3.1 Pareto chart

Pareto chart can show the most frequent types of defects to bottled tea primary packaging. In this research, the data were sampled based on observation in 2018. The samples were taken periodically from the production process. The cause of failures could come from the operators, machines or raw materials. Quality control from the control of raw materials to finished products has been carried out by the company, but there are still products that are damaged during the production process. The data on total production and number of products damaged in 2018 can be viewed in Table 1.

Table 1. Number of production and damaged bottled tea in 2018.

| Month     | Total production | Type of Damage | % |%
|-----------|------------------|----------------|---|---
|           |                  | Preform defects | Odd Materials | Broken caps | Conveyor problems |
| January   | 5,254,743        | 133,470        | 25,223        | 32,054      | 11,035          | 3.84 |
| February  | 3,408,274        | 71,915         | 13,292        | 29,311      | 20,109          | 3.95 |
| March     | 2,160,606        | 37,811         | 9,291         | 16,853      | 8,210           | 3.34 |
| April     | 4,059,504        | 45,466         | 17,456        | 28,417      | 13,396          | 2.58 |
| May       | 4,411,008        | 52,050         | 14,997        | 35,729      | 11,469          | 2.59 |
| June      | 1,939,934        | 22,309         | 6,596         | 10,476      | 5,626           | 2.32 |
| July      | 5,096,108        | 35,673         | 13,250        | 30,577      | 8,663           | 1.73 |
| August    | 4,756,665        | 37,578         | 24,735        | 25,686      | 7,611           | 2.01 |
| September | 2,164,476        | 27,489         | 4,762         | 23,376      | 3,680           | 2.74 |
| October   | 4,766,933        | 39,089         | 10,487        | 32,892      | 8,104           | 1.90 |
| November  | 5,797,565        | 38,844         | 8,117         | 33,046      | 11,595          | 1.58 |
| December  | 5,052,429        | 33,346         | 7,579         | 30,820      | 10,105          | 1.62 |
| TOTAL     | 48,868,244       | 575,039        | 155,784       | 329,236     | 119,602         | 30  |
| % Defect  |                  |                | 48.7          | 13.3        | 27.9            | 10.1 |

Figure 1. Pareto chart of type of damage.

Table 1 shows that the highest defects were found in January by 3.84% and February by 3.95%. This could be affected by the operational processes at the beginning of the year that caused the machine, and worker performance was less than optimal. Also, in January and February 2018 was a rainy season. This rainy season indirectly affected the quality of preform stored in storage sheds. The humid weather in the rainy season caused preforms that are stored to have a high humidity level. Therefore, during the blowing process, the preform becomes fragile and easily damaged due to high moisture content. Figure 1 shows
the Pareto diagram that shows the largest types of damage that occurred during the tea production process in 2018 is from preform defect.

From the four types of damage to the primary packaging of tea products during January-December 2018, it is distinct that the highest damage was in the defective preform. The number of defective preforms was 575,039 or 48.7%. Then, the broken caps were 329,236 or 27.9%. Meanwhile, the odd materials were about 155,784 or 13.3%, and the last was the conveyor issues by 119,602 or 10.1%. Consequently, it is concluded that the company needs to control the problem of preform defects even further because of its considerable impact on the amount of damage to the primary packaging of tea products. Control can be conducted from handling the raw materials to finished products. Quality standards include the raw materials, production processes and finished products. Therefore, quality control activities can be performed from the raw materials, during the production process, until the adjustment of the final product to the predetermined standards [8].

Defective preforms can be controlled by conducting more strict supervision during the incoming process or receiving the raw materials at GMT and monitoring the preform during storage. The preforms imported by suppliers must be checked more carefully so that if there was damage, could be immediately complained. Moreover, the preform storage temperature and preform storage period must get careful attention with the expectation that no preform has high humidity. Preforms that have high moisture will deform in the blowing process.

3.2. Laney P chart

After finding out the amount of existing damage, the data was analyzed to determine the extent to which the damaged product was still within the limits of statistical control through the control of "Laney P chart". This control chart was a map developed from the control P chart. In processing the data, the Laney P Chart was utilized since the number of samples was too large, causing the control boundaries between CL, UCL and LCL to be very narrow or close together. In this case, if the data was processed using the usual p control chart, there will be error data, and all data will be out of control. Laney P control chart is a control chart that uses sigma Z in the data processing. The use of Sigma Z aims to adjust the existing values so that the appropriate upper and lower control values that are not close together can be obtained. Data processing with the "Laney P chart method" using the Minitab 18 application and the data from Laney P Chart results can be seen in Figure 2.

![Figure 2. Laney P chart of the reject number.](image)
According to the data displayed from the results of processing with the Laney P Chart method, it can be viewed that in this map, the CL (Central Line) value was 0.02414, the average value of UCL (Upper Control Line) was 0.03449, and the average value of LCL (Lower Control Line) was 0.01379. UCL is the upper limit for an acceptable deviation, CL is a line that represents no deviation from the sample characteristics, and LCL is the lower boundary for a deviation from the sample characteristics.

3.3. Fishbone diagram

Cause and effect diagrams show the relationship between the problem on hand and its possible causes as well as the factors that influence them. The purpose of this diagram is to recognize the root cause of a problem or the underlying cause of a particular effect, problem or condition. This diagram also serves to sort out and describe the interplay between various factors that influence a particular process. While the benefits of this diagram are to increase knowledge about the process being analysed and learn more about work factors and how these factors are interrelated. The cause and effect diagram of damage to the primary tea packaging can be seen in Figure 3. Figure 3 shows that four factors were affecting the primary packaging damage, which in general are machine, process, material and environment.

In terms of the machine, an insufficient amount of nitrogen pressure exerted by the filling machine can cause the bottle to become dented or under pressure. The high level of damage to the process resulted from machine performance that was not optimal, so it is necessary to control it by approaching method to find and reduce the factors that lead to disabilities and errors [9]. In this case, the bottles frequently fell off the conveyor line because there were too many bottles in this line. To produce quality products, companies need to pay attention to the operating system that takes place by measuring and calculating the time and standard output in one production [10]. In terms of the material, the most significant damage on the primary packaging was generated by supplier error. One of the determining factors to ensure the production process is the raw material. The environment can be a factor in preform damage [11]. If it is stored for a long enough time, the humidity level will be higher. As a consequence, the quality of the preform will decrease, and during the blowing process, the preform that is too humid cannot be adequately printed or becomes defective.

![Figure 3. Cause and effect diagram of primary tea packaging.](image-url)
3.4. Failure mode and effect analysis (FMEA)

The proposed alternative improvements referred to the results of the FMEA method. The FMEA method was employed to select the most dominant risk that causes failure in the tea packaging process. Based on the seven risks that were obtained from the fishbone diagram, interviews were then conducted with the head of the packaging unit. Then, five alternative improvements that are the most suitable with the ability of the company to solve these problems are chosen, which can be noticed in Table 2.

| No | Risk process | Possible Effect | Possible cause | Control |
|----|--------------|-----------------|----------------|---------|
| 1  | Less pressure during the blowing process | Dented bottle | Lack of amount of nitrogen pressure released | check and ensure that the measurement |
| 2  | The bottle fell from the conveyor | Bottle falls | Bottles that fall from the conveyor because too many bottles in the conveyor | regulate the number of bottles produced so that the bottles arranged in the conveyor are not crammed and are not easily dropped |
| 3  | High humidity in the environment | Preform defect | High preform humidity levels | Pay attention to room temperature and preform placement |
| 4  | Preform Defect | Preform defect | supplier error | Handling raw materials properly during the incoming process. |
| 5  | Odd Materials | There are odd materials in the preform | Process of forming the preform from the supplier. | Handle the right raw materials during the incoming process. |

In regards to the calculation of risk, the first thing to do was to provide assessment criteria for the level of severity, occurrence, and detectability from level 1 to 10 by experts or employees who are experts in the field. In this case, the author requested four experts, namely Company X’s quality control employees to fill in the assessment criteria because they were responsible for the quality of the packaging. The selection of respondents must be based on the consideration that the respondent has a direct relationship with the process and is an employee who has long work experience [12]. After filling the questionnaire, the processing results using FMEA were obtained. The data is presented in Table 3.

| No | Risk identify | S  | 1 | 2 | 3 | 4 | O  | 1 | 2 | 3 | 4 | D  | 1 | 2 | 3 | 4 | RPN |
|----|---------------|----|---|---|---|---|----|---|---|---|---|----|---|---|---|---|-----|
| 1  | Preform Defect | 8  | 7 | 5 | 4 | 7 | 7 | 7 | 7 | 6 | 6 | 7 | 9 | 294 |
| 2  | The bottle fell from the conveyor | 9  | 5 | 5 | 4 | 7 | 6 | 5 | 6 | 3 | 7 | 6 | 6 | 189.75 |
| 3  | High humidity in the environment | 9  | 6 | 5 | 3 | 7 | 5 | 4 | 6 | 3 | 7 | 7 | 6 | 181.64 |
| 4  | Less pressure during the blowing process | 7  | 4 | 6 | 5 | 6 | 3 | 6 | 5 | 3 | 4 | 7 | 6 | 137.5 |
| 5  | Odd Materials | 4  | 4 | 4 | 2 | 4 | 4 | 4 | 5 | 3 | 8 | 6 | 5 | 81.81 |
Based on the data processed using FMEA, the results show that the main risk of the tea packaging process is a defective preform with an RPN value of 294 was due to the supplier errors. Consequently, the solution can be carried out by handling the raw materials properly during the incoming process. Workers should pay more attention in detail to the quality of preforms received from the suppliers. One of the determining factors for the success of the production process is raw material. In the case of procurement of raw materials, companies need to make efforts to search and select raw materials that will be used for the production process carefully [13]. Careful selection of raw materials is conducted so that companies use quality raw materials and avoid defects; hence, they can produce quality products.

4. Conclusions
The quality control of primary bottled tea packaging at the company is reasonable because the number of defects that occur is low. Based on analysis using SQC, the highest number of defects occurred in January and February. The preform defect has the highest amount of damage of 48.7%. The results of the risk analysis using FMEA show that defective preforms are the main risks that need to be controlled due to supplier errors. Therefore, proper handling of raw materials during the receiving process is essential. Careful selection of raw materials is made so that companies use high-quality raw materials and avoid defects so they can produce quality products.

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