Analysis on Product Quality of Semi Refined Carrageenan using Six Sigma and Cost of Poor Quality

Analisis Kualitas Produk Semi Refined Carrageenan dengan Metode Six Sigma dan Cost of Poor Quality

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Abstract

The study aimed to minimize defective products to improve the production process quality of PT BI by identifying the most types of defects, calculating Defect per Million Opportunities (DPMO) value, suggesting the quality improvement of the Semi Refined Carrageenan (SRC) production process, and calculating Cost of Poor Quality (COPQ) value. The methods used in this research were Six Sigma and the COPQ. The priority improvement based on the Pareto chart was moisture defects with the percentage of damage of 36.9%. The Sigma level of the production process of PT BI was 3.42 with a defect rate of 27,429 DPMO. The analysis on the cause and effect diagram showed that factors affected the occurrence of defective products were error in reading on moisture content, diverse raw material, the wrong method of mixing raw materials prior to production process, and the lack of inspectors of production process. The most influential-dominant factor was the obsolete machine which causes error in reading on moisture content. The company can take preventive and corrective actions to suppress defective products and improve product quality. Based on the calculation of the COPQ, the costs that must be incurred by the company due to defective products was IDR 1,007,690,694.

Keywords: Cost of Poor Quality (COPQ), quality control, seaweed, Six Sigma

INTRODUCTION

Nowadays many demands put forward by consumers; however, quality is the only one main thing that plays the biggest role. It is the consumer’s main demand. The increasingly market competition also makes the framework of thinking about improving quality not only limited to provide products according to consumer needs but also be accompanied by efforts to reduce all costs to achieve the expected quality (Hansen & Mowen, 2006).

Seaweed is a group of marine plants that has indistinguishable characteristics among the roots, stems and leaves that the whole parts of seaweed are called talus (Ferawati, Widyartini, & Insan,
2014). *Eucheuma cottonii* is one of the types of seaweed that can be cultivated. It is the type of seaweed that is most commonly cultivated for an ingredient in food manufacturing, medicinal mixtures and cosmetics (Rismawati, Salengke, & Tulliza, 2012).

PT BI is a company which engaged in seaweed processing industry. It cultivates seaweed for export, but it has encountered many product defects. Therefore, it has become an absolute demand for PT BI to maintain product quality and respond consumer demands. The purpose of this study is to identify the types of defect in the production process, to calculate the sigma value and the total quality cost in the aspect of Cost of Poor Quality (COPQ), to identify the factors that cause defective products and to provide recommendations and suggestions to minimize the defects and COPQ.

**METHODS**

Research was conducted in PT BI by data which were obtained from primary data (interview process) and secondary data (number of production unit in 2017-2018 period and data regarding employees’ activity of work in the company). Observation was made on processed seaweed products of Semi Refined Carrageenan (SRC) produced by PT BI.

SRC is a carrageenan product with a lower purity level than refined carrageenan for it still contains cellulose which also settles with carrageenan. SRC is commercially made from *Eucheuma cottonii* through a process using alkaline solution (potassium hydroxide/KOH). According to the Research and Development Center for Marine and Fisheries Biotechnology and Product Processing (Balai Besar Penelitian dan Pengembangan Pengolahan Produk dan Bioteknologi Kelautan dan Perikanan, 2013), SRC extracted from *Eucheuma cottonii* seaweed has following contents provided in Table 1. Research flowchart can be seen in Figure 1.

**Six Sigma**

Six Sigma strategy aims to improve business performance by reducing various unfavorable process variety, reducing production or process failures, suppressing production defects, increasing profit, boosting morale of personnel or employee, and improving product quality at a maximum level (Gaspersz, 2005). It is a very effective...

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**Table 1. Specification of semi refined carrageenan**

| Parameter          | Specification |
|--------------------|--------------|
| Yield (%)          | 38.50        |
| Water Content (%)  | 5.50         |
| Ash Content (%) wb | 0.20         |
| Acid Insoluble Ash | 0.27         |
| Sulfur Content (%) | 17.69        |
| Viscosity (cPs)    | 250.00       |
| Gel Strength (g/cm²)| 1,009        |

(Source: Balai Besar Penelitian dan Pengembangan Pengolahan Produk dan Bioteknologi Kelautan dan Perikanan, 2013)
principle and technique in implementing quality testing (Pyzdek, 2003). Moreover, it is almost complete in meeting customer requirements as its purpose (Pande, Neuman, & Cavanagh, 2002). Six Sigma, hence, is an important means for production management to maintain, improve and preserve product quality, particularly to achieve quality improvement towards zero defects. Five stages to implement quality improvement using Six Sigma are using the DMAIC method, namely Define, Measure, Analyze, Improve, and Control (Pande & Holpp, 2001). In this study, the five stages of DMAIC analysis at PT BI are described as follow:

Identification of Problems (Define)
Define stage is the goal setting of Six Sigma quality improvement activities. This stage is to define the action plans that must be taken to perform the improvement of each stage of the key business processes (Gaspersz, 2005). At the define stage of a quality problem in the production of SRC, the causes of defective products were defined. Potential causes of defects which were laid on the production of SRC products will as well be explained, namely moisture content, gel strenght and granules content.

Measure
Measure is a logical follow-up to the define stage which will be a bridge to the analyze stage. This step focuses on understanding the performance of the current improved process, as well as gathering all the required data for analysis (Gaspersz, 2005). At the measure stage, control maps is commonly used. By using this tool, it will be known the final result which deviates from the upper limit or the final limit of the product criterion set by the company (Syukron & Kholil, 2013) in the measure, which is as follows:

1. Determination and Ordering Primary Critical To Quality (CTQ)
   At this stage, the management must know the most potential company’s internal processes that have great potential to affect the quality of output (CTQ) first. Then the management measures the amount of deviation occurred compared to the quality raw material specified in the CTQ. This means that at this stage we must know the failure or defect occurred in the product or process that we are going to fix.
2. Measurement of Process Stability
   This stage will serve proportion value, CL (Central Line), UCL (Upper Control Limit), and LCL (Lower Control Limit).
   a. Calculating Defect Percentage
      \[ p = \frac{np}{n} \]  
   b. Calculating Central Line (CL)
      \[ CL(p) = \frac{\text{number of defective product}}{\text{number of production}} \]  
   c. Calculating Upper Control Limit (UCL)
      \[ UCL = p + 3 \sqrt{\frac{p(1-p)}{n}} \]  
   d. Calculating Lower Control Limit (LCL)
      \[ LCL = p - 3 \sqrt{\frac{p(1-p)}{n}} \]
3. Measurement of Level of Six Sigma and Defect per Million Opportunity (DPMO)
   a. Calculating DPU (Defect Per Unit)
      \[ DPU = \frac{\text{Total Defect}}{\text{Total Production}} \]  
   b. Calculating DPMO (Defect Per Million Opportunities) Value
      \[ DPMO = DPU \times 1.000.000 \]  
   c. Level of Six Sigma
      To determine sigma level of production is made by converting DPMO to Sigma value (Syukron & Kholil, 2013).

Analysis of the Cause of Problem (Analyze)
Analyze stage of DMAIC function is to provide suggestion to which priority as an effort to overcome causes of the problem, show the impact of process failures and final products on consumers, describe the causes of failure to the root causes of problems and provide suggestions for improvisation efforts (Tannady, 2015). The category of sources of the defect was identified by a cause and effect diagram.

Suggestions to Maintenance Plan (Improve)
An action plan is implemented in this stage to fulfill Six Sigma quality improvement. The Six Sigma quality improvement team must decide on targets to be achieved, why the action plan is carried out, where the action plan will be carried out, who is responsible for the action plan, how to carry out the action plan and how much the implementation cost and how big positive benefits implementation of the action plan is (Susetyo & Hartanto, 2014).

Control
Control is the last operational stage in an effort to improve quality based on Six Sigma. At this stage the results of quality improvement are documented and disseminated, successful best
practices in improving the process are standard-
ized and disseminated, procedures are docu-
mented and used as standard guidelines, and own-
ership or responsibility is transferred from the
team to the owners or processors in charge
(Susetyo & Hartanto, 2014).

Cost of Poor Quality

According to Horngren, Datar, & Foster
(2009) cost of quality is the cost incurred to pre-
vent low quality products, or is a cost that arises
as a result of producing a product that has low
quality. Quality control costs are measured in two
segments, namely: prevention costs and appraisal
costs, while quality control failure costs consist
of internal failure costs and external failure costs
(Feigenbaum, 1991).

Costs of poor quality are costs due to inabil-
ity of products and processes to meet the quality
standard requirements (Gryna, 2001). According
to Gryna (2001) costs of poor quality include:
1. Internal failure costs
   Internal failure costs are costs incurred due
to inability to meet customer requirements
or needs and due to inefficient processes as well.
2. External failure costs
   External failure costs are the costs of mis-
matching a product or service following the
consumer’s product receipt, including costs
resulting from lost sales opportunities.

RESULTS AND DISCUSSION

Quality Control by Six Sigma Method

The application of quality control used in
this study was the Six Sigma method through five
stages of analysis; define, measure, analyze, im-
prove, and control at PT BI in the production of
SRC.

Identification of Problem (Define)

Production process of SRC at PT BI was
started from *E. Cottoni* seaweed weighing, wash-
ing, cooking (softening process), rewashing
twice, cutting, rewashing, drying, sorting,
milling, and packing. The results of observation
in the production line and interview with quality
department of PT BI showed the frequently
occurred defects was unsuitable moisture and gel
strength as well as excessive granules content.
The standards used can be seen in Table 2.

| Defect type | Assessment Standard Based on |
|-------------|------------------------------|
|             | SNI No. 2690.1:2009 BBP4BKPT PT BI |
| Moisture Defect (%) | 30 12 <15 |
| Gel Strength Defect (g/cm²) | 1,000 1,009 700 |
| Granules Defect (%) | 5 1 1 |

| Defect Type | Defect amount (Kg) | Percentage (%) | Cumulative (%) |
|-------------|-------------------|----------------|---------------|
| Moisture Defect | 3,325 | 39.6 | 39.6 |
| Gel Strength Defect | 2,650 | 31.5 | 71.1 |
| Granules Defect | 2,425 | 28.9 | 100.0 |
| Total | 8,400 | 100.0 |

Figure 2. Pareto Chart of PT BI Production Defect

Measure

Measure stage is intended for obtaining in-
formation about value of strategic measurement
for further stage. Steps to calculate are as follow:
1. Determination and Ordering CTQ Priority
   Based on the data obtained, potential Critical
to Quality (CTQ) which has been met by PT
BI were showed in Table 3. Pareto chart
(Figure 2) shows frequency of the most
dominant defects namely moisture defect of
39.6%, gel strength defect of 31.5% and
granules defect of 28.9%. Pareto chart does
not only show relative size of the quality rat-
ing, but also as helpful visual means
Analysis on Product Quality

Blocher, Stout, & Cokins (2011). It, moreover, serves in identifying the main cause of low quality so as the management is able to focus on quality improvement efforts which correspond to the most influential aspect.

2. Measurement of process stabilization

According to the calculation, then, further action was conducted to make control chart p as in Figure 3 and Figure 4. Criteria used in p-chart are:

a. If \( P < \text{LCL} \), it means the samples came down outside lower control limit (LCL) then inspect its cause.

b. If \( \text{LCL} < P > \text{UCL} \), it means that all samples are within control limits and it is called they act normally or having good process capability.

c. If \( P > \text{UCL} \), it means that samples came out outside upper control limits (UCL) or it is classified as low process capability then inspect its cause and take corrective action through performance improvement of production process.

According to the figure, it is showed that P (proportion defective) is mostly outside control limits, then it can be said that process capability did not run smoothly/low so that it is not able to declare process capability has fulfilled the specification of expected tolerance limit. If there is no data off the upper control limit (UCL) or lower control limit (LCL) as well as data plots did not show any deviation indicator then the process is in under control. If the data off the control limits, on the contrary, then it is called uncontrolled process, so it requires corrective actions so as the defective products can be prevented. Measurement data that caused uncontrolled process or extreme data needs to be eliminated accordingly in order to continue calculation of process capability. The extreme data in question are data of March 2017, August 2017, November 2011, February 2018, July 2018 and November 2018. After eliminating extreme data, recalculate process stability is further step to obtain process data that is within control limits.

Based on the p control map in Figure 4, it shows that the process is in a stable state for they are within control limits. As long as the points are within control limits, the process is considered controlled, if the data pattern is random, on the contrary, it can be said to be uncontrollable.

3. Measurement Six Sigma Level and Defect per Million Opportunity (DPMO)

According to calculation in the production department of PT BI especially SRC production, it has sigma level of 3.42 with defective probability of 27.429 for one production. This is likely to be a big loss if it is not handled because more failed products in the production process, surely, will result production costs overrun.

**Analysis Cause of Problem (Analyze)**

In this study, Fishbone Diagram was used (Figure 5) to determine the cause of the defects. If the causal relationship of the problem is known, problem-solving actions are easy to determine. Causes of the problem are grouped into 5 main factors, i.e., humans, machines, materials, methods and environment.

1. Human

Defective product which is usually found in the production process was due to lack of worker (Inspector) who performs checking process so that it frequently experienced errors in recording moisture content.
2. Machine
Machines are the main tools to support production process. Problems of machine that cause product defects was machine made errors in reading the gel strength and moisture content. This is due to the lack of regularity of maintenance process and its old life.

3. Material
Main factor that caused defective product in the production process of PT BI was the great number and type of materials which mostly used that resulted different content of gel strength and moisture. By the great number of materials used in one production, hence, it was difficult for the machine to read the content of these materials.

4. Method
Using good working method will definitely reduce number of defective products. And if it uses poor working method, on the contrary, will result higher probability of defective product produced. In the production process, all of materials (seaweed) that processed into flour will be mixed so that it was sometimes resulted change in moisture content which did not match to production standard.

5. Environment
Company’s neighborhood that directly or indirectly affected the company in general and the production process in particular.

Suggestion to Improvement Plan (Improve)
It is required to set a recommendation or suggestion for improvement after knowing the cause of defect of SRC product. The improvement to suppress level of defective product are provided in Table 4.

Cost of Poor Quality
The following is the result of identification of various costs incurred by PT BI in 2017-2018 for activities related to quality in producing products that meet specified quality standards. Classification on quality cost of the company is according to concept of quality cost category (Gryna, 2001).

Cost of control in 2018 according to the Table 5 experienced reduction of IDR 1,950,000 it is, moreover, the result of difference from the total cost of control in 2017 of IDR 21,203,571 and the total cost of control in 2018 of IDR 19,253,571. COPQ experienced contrarily, it increased IDR 1,007,690,694 in 2018 i.e. the difference of the total of COPQ in 2017 IDR 516,450,193 and total of COPQ in 2018 that is IDR 1,524,140,887.

The increase of COPQ considered as company’s incapability to minimize number of defective unit through quality improvement activities that increased cost of control. The reduction of costs of control incurred, however, was more than the increase of COPQ obtained. The reduction of failure cost, on the other hand, should be more than the increase of cost of control; hence, cost incurred by company could eventually be more efficient.
Table 4. Suggestion to improvement

| Element            | Causative Factor                                      | Recommendation                                                                 |
|--------------------|-------------------------------------------------------|---------------------------------------------------------------------------------|
| Raw Material       | 1. Quality of material that did not meet standards     | 1. Strictly sorting the raw materials that get in the company                    |
|                    | 2. Diverse kind of material and in a great number      | 2. Record and label each seaweed; mass, type, origin, number, the date and store it according to its type |
|                    | 3. The temperature does not fit to the conditions either at the storage or in the production process | 3. Install thermostat to maintain temperature of each production process.         |
| Method             | 1. Laboratory procedure which is not updated           | 1. Update laboratory procedures                                                  |
|                    | 2. Lack of Sorting process and washing.               | 2. Use water spray to improve washing effectiveness. After soaking in water, the cage which was filled with seaweed then remove and spray it from the side to reduce water usage. |
|                    | 3. Incomplete drying process                          | 3. Improve dirt separation process (sand, gravel, etc.) by installing screen separator with vibration. |
|                    |                                                       | 4. Replacing sun drying with mechanical drying by using a rotary drum will increase work efficiency because mechanical drying does not depend on weather conditions so that the drying process can be completed in 1 day. |
| Tools/Machine      | 1. Machine life                                       | 1. Check machine settings periodically and perform calibration                   |
|                    | 2. Lack of machine maintenance                        | 2. Repair the damaged machines, perform maintenance on machines intensively and continuously |
|                    | 3. Error in reading content                           | 3. Operate the machine consecutively or add more machine                        |
| Human              | 1. Disobey the rule                                   | 1. Provide training and warning to workers so they do not make any mistake      |
|                    | 2. Lack of discipline                                 | 2. Conduct intensive inspections of employees by supervisors                     |
|                    | 3. Many inspections were carried out                  |                                                                                 |
| Environment        | 1. Dusty condition of factory                         | 1. Install the cover and reservoir around the output of milling machine to catch SRC that float and to not scattered on the floor so that it can be recovered |
|                    | 2. Uncertain weather                                  | 2. Install a control parameter                                                  |
|                    |                                                       | 3. Use automatic machine for drying process                                     |

Table 5. Total and percentage of quality cost

| Quality Cost          | 2017            | 2018            | 2017   | 2018   |
|-----------------------|-----------------|-----------------|--------|--------|
| Cost of Control       |                 |                 |        |        |
| Prevention Cost       | IDR 14,507,143  | IDR 12,557,143  | 2.61%  | 0.80%  |
| Appraisal Cost        | IDR 6,696,429   | IDR 6,696,429   | 1.21%  | 0.43%  |
| Cost of Poor Quality  |                 |                 |        |        |
| Internal Failure Cost | IDR 516,450,192 | IDR 1,524,140,887 | 96.18% | 98.77% |
| External Failure Cost | IDR 0           | IDR 0           | 0%     | 0%     |
| Total                 | IDR 537,653,764 | IDR 1,524,140,887 | 100%   | 100%   |

COPQ proportion of the total of quality cost of the company is presented at Table 5. According to the table, the proportion of COPQ that consists of internal and external failure cost were up to 90% of the total quality cost. It is showed that the company has opportunity to minimize COPQ by performing quality improvement activities that will eventually increase cost of control (Hansen & Mowen, 2006).

If Six Sigma was implemented, it would be very influential for PT BI. It was proven by availability of substantial COPQ. The lower the COPQ value obtained then indicates relatively small failure management costs in the process as well. This means that the process is able to produce good quality products, and the higher achievement of a sigma level of the process.
CONCLUSION

Types of defect laid on the production process of PT BI in 2017 and 2018 were moisture content, ash content, gel strength, sulfur content, viscosity and granules content. The research, however, only focused on three types of defect namely moisture content, gel strength content and granules content since flour composition produced did not represent the content level it should. Defect per million opportunities (DPMO) values of PT BI Mills in 2017 and 2018 was 6,100 kg of defective products per one million productions. Currently, the company has sigma value of 3.42 it means there are approximately 27,429 of defective products in one million productions, it, moreover, is categorized good compared to industry standard in Indonesia i.e. 308,537 of defective products per one million productions. Besides, the COPQ company must incur due to defective products in 2017 was IDR 16,450,193 and IDR 1,524,140,887 in 2018.

Factors affected the occurrence of defective products were error in reading on moisture content, diverse raw material, the wrong method of mixing raw materials prior to production process, and the lack of inspectors of production process. The most influential-dominant factor was the obsolete machine which causes error in reading on moisture content. The improvement to reduce the level of defective products should apply to the most dominant factor that contributed to the cause of defect. The machine should have a good maintenance and calibration to maintain it function optimally. Paying attention to COPQ can increase the company’s profit so that it has an advantage in competing with its competitors.

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