Defects analysis of frozen fish steak processing using six sigma: a case study

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Abstract. Six Sigma has been utilised to analyse defects of fish steak processing at PT X located in North Jakarta. The tools of the Six Sigma implemented in the study were Define, Measure, Analyse and Improve. The observation was conducted for two months in 2020 before the company was temporarily shut down due to Covid-19 pandemic. Four defects were detected during the study, ie under size fish, softened meat, off odor and green coloration of meat, totaling 2,446 kg out of 15,080 kg of fish. Further analysis showed that the Sigma level was 3.24 with a Defect per Million Opportunities (DPMO) of 40,739. Some improvements were recommended based on cause-effect diagram.

1. Introduction
Fisheries industry is a lucrative business and plays important roles in the economy of many developing countries such as Indonesia. It also serves as both a source of livelihood and food security to the people. Also, seafood is considered the most traded food commodities in the world, and the value of its annual global export showed an increasing trend. In the years of 1976 to 2018, the value increased from USD 7.8 billion peaking at USD 164 billion, with an annual growth rate of 8 percent in nominal terms or 4 percent after adjusted for inflation [1]. This contributes about 11 percent to agricultural products. Being the second largest global fish production, Indonesia exports fish and fish products at value of up to USD 5 billions annually, of which the majority is in frozen state. The fish is exported in various forms such as whole, cube, fillet, saku, steak, chunk, and loin or in processed forms such as canned fish, while the species includes tuna, snapper, mackerel, skipjack, barramundi, emperor fish, yellow tail, pomfrets and others. There are more than 60 thousands fish processing plants in Indonesia, of which about 700 are big scale companies that actively process and export fish to international markets.

Competition in the global seafood market is very tight, while strict requirements in quality and safety are imposed by importing countries such European Union, Japan and United States. This has made seafood industries put extraordinary effort to improve the process quality to meet such requirements by finding and implementing a way in optimization of the process to win the competition. Implementing new tools and quality programs are a challenge for the seafood industry, which require commitments not only by the management, but also the entire personnel in the company. There are some tools that have been widely implemented including Six Sigma which is a tool to analyse defects and recommend improvements so that the product or services can meet the consumer’s expectation.

Launched in 1987 by Motorola [2], Six Sigma has gained popularity in improving process quality
of many products and services [3, 4], and also is regarded as one of the most popular quality initiatives in the industrial sectors [5]. As an improvement strategy, Six Sigma is implemented to identify and eliminate the causes of defects or errors, and to improve efficiency and effectiveness of the business processes [6]. Six Sigma is regarded as the best method for quality improvement [7] and has received considerable mentions in the literatures after its introduction in 1987 [5, 8, 9]. The method is implemented through steps namely Define, Measure, Analyse, Improve and Control (DMAIC), which can be implemented within 1-3 months, depending upon purposes and scopes. Not only that this tool is suitable for large companies, but also has been successfully implemented for small and medium enterprises [10, 11, 12, 13].

In Indonesia, Six Sigma has also been successfully implemented to analyse and reduce defects in the fish processing industry [14, 15, 16, 17], but none has been done on frozen fish steak. The existing paper reports the use of Six Sigma to analyse defects of frozen fish steak processing in a fish processing plant located in North Jakarta. The company processes many types of frozen products from various fish species and needs to eliminate quality defects of the products.

2. Materials and Methods

2.1. Materials

The study was conducted at PT X, a frozen fish products company in North Jakarta. The company processes various fish species into a number of frozen products such as fillet, steak and cube. The raw materials are obtained from suppliers and from their own fishing vessels. The products are mainly exported to USA, Russia, Japan, China and the Middle East. Emperor fish (Lethrinus lentjan), one of the fish species processed in the processing plant, was chosen as an object of the study. The observation was performed during March-April 2020.

2.2. Methods

Six Sigma methodology was used in this study following the guide from The Council for Six Sigma Certification [18], and its implementation for fish [14, 15, 16]. Analysis was carried only for DMAIC and not for C as the company temporarily stopped its operation and was not accepting visitors due to Covid-19 pandemic for several weeks. Data and information were obtained through direct observation during the process, followed by deep interviews with tally and discussion with Quality Assurance Officer, for 2 months (February-March 2020).

3. Results and Discussion

The company received emperor fish as raw material in whole-frozen form, mostly originated from eastern Indonesia. The size of the fish varied from 0.3 to 2 kg, categorized into 3 classes, ie 0.3-0.5, 0.5-1 and >1 kg. Fish of 0.3-0.5 kg in weight was for WGGS (Whole, Gilled, Gutted and Scaled) product, while 0.5-1 kg was for WGGS and fillet. Those having weight of more than 1 kg were processed into steak. During two-month observation, 23 batches of emperor fish were processed into steak. The weight of the batches ranged from 550 to 1,080 kg, totaling to 15.1 tonnes with an average of 655.1 kg per batch. The processing of frozen fish steak is as shown in Figure 1.
3.1. Define
Observations were made at every step of the process and found 4 defects when compared to Critical to Quality (CTQ). The defects were under size fish, soft meat, off odor and greening meat, which were depicted in table 1./

3.1.1. Defect 1. The first defect was under size fish which was observed in weighing II. This indicates that the first weighing after receiving was not accurate. Under size fish, ie < 1kg, will affect the steak yield as the amount of meat is less.

3.1.2. Defect 2. This defect was detected when the fish was given a finger pressure, the meat did not return to the original position. A normal fresh fish will have firm but elastic meat. Fish with soft meat is easy to be torn up and unsuitable for steak as this will affect the yield and quality.

3.1.3. Defect 3. Off odor was present in washing and steak forming steps of the processing line. This indicates that at these steps, the fish has deteriorated as off odor is a result of meat decomposition, especially by microorganisms. Such meat was separated and could not be further processed into the next step.

3.1.4. Defect 4. Good quality meat should be red in color, and greening is a sign of deterioration. It has long been known that greening of meat in deteriorating fish was due the reaction of myoglobin pigment, TMAO (trimethylamine oxide) and cysteine the dark meat [19, 20]. In our observation, meat with green color was detected in finishing step.

Table 1. Observed defects and CTC in emperor fish steak processing.

| Processing step   | Critical to Quality       | Defect              |
|-------------------|---------------------------|---------------------|
| Weighing II       | Fish size ≥1kg/pc         | Fish size < 1kg/pc  |
| Dressing          | Firm meat                 | Soft meat           |
| Washing           | No odor or specific to fish | Off odor          |
| Steak forming     | No odor or specific to fish | Off odor          |
| Finishing         | Red color meat            | Greening meat       |
3.2. Measure

The data for defects during our observation is as shown in table 2, which indicates that the percentage was 16.4%. It can be seen that undersized fish dominates the defects, which accounted for up to 31.3% followed by soft meat 27.8%, off odor 22.7% and greening meat 12.4%. Measurement was then continued for defect control chart and process capability, of which the results are presented in figure 2 and Table 2.

Table 2. Summary of defects, control limits and process capability in emperor fish steak processing.

| Observations | 23 |
|--------------|----|
| Production (kg) | 15,080 |
| Defect (kg) | 2,466.3 |
| Under size | 918.9 |
| Soft meat | 684.5 |
| Off odor | 559.4 |
| Greening meat | 303.5 |

Pareto
- P: 0.163
- CL: 0.161
- UCL: 0.204
- LCL: 0.118

Process capability
- DPU: 0.163
- DPO: 0.041
- DPMO: 40,739.7

Sigma level: 3.244

As shown in figure 2, the Lower Control Limit (LCL) and the Upper Control Limit (UPL) were 0.118 and 0.204 respectively, while the central line (P) was 0.163, and the defect line was between the limit lines. Moreover, there were no six consecutive points increasing nor decreasing and no fourteen consecutive points that were alternately up and down that are usually used as indicators of out of control process. Thus, it can be said that the process was in control. However, improvements were necessary as the level of defects was still quite high, ie. 16.3%. This was also supported by the result of process capability measurements as shown in table 2, where the Defect Opportunity per Million Opportunity (DPMO) was 40,740 with a Sigma Level of 3.24, far below the ideal level of 6.

Widjajanto and Purba [21] have reviewed 52 papers on the Sigma Level of the Indonesian manufacturing industry which were published in the 2016-2020 period, and concluded that the average Sigma Level is 3.68, which is slightly higher than the Sigma Level in this study. There are 7 food industries on the list and it is reported to have an average Sigma Level of 3.4. The Sigma Level for frozen fish steak this reports (3.24) is in the range of Indonesia's fish processing industry levels, ie. 2.95-4.52 [14, 15, 16, 17, 22].
3.3. Analyse
To determine the causes of defects that are going to be rectified, pareto analysis was conducted and the results are depicted in Figure 3. Based on 80/20 pareto analysis [22], it was revealed that the defects amounted to 80% were undersize fish (31.3%), soft meat (27.8%) and off odor (22.7%). Further analysis using a fishbone diagram was then conducted. Soft meat and off odor (and greening meat) are indications of quality deterioration [24, 25]. Therefore, in the fishbone analysis, both defects were combined, as practically the causes and effects could be similar. The results are presented in Figure 4.

![Figure 2. Control chart for defects in emperor fish steak processing.](image)

![Figure 3. Pareto chart for defects in emperor fish steak processing.](image)
3.4. Analyse

Based on figure 4, four causes that led to the defects were identified, namely man, methods, environment and machine. Discussion with Quality Assurance Department resulted in a series of recommendations for improvements as follows:

3.4.1. Man. The problem most faced was the attitude of employees who were careless and undisciplined if not attended by a supervisor, and did not follow instructions. A situation that was also observed in a similar fish industries in Denpasar, Bali [14], Jakarta [15], and Pasuruan, East Java [16]. This was coupled with the fact that they lacked necessary skills, and qualification, in addition to the limited experience. There was no bonus system which added to the situation resulting in a lack of motivation to work. To overcome the problems, training was the first thing that could be done. This includes not only in technical matters such as Good Manufacturing Practices (GMP), or machines/equipment operations, but also in Sanitation Standard Operating Procedures (SSOP). Ignoring SSOP has resulted in the fast deterioration of products. New employees must be assigned a job gradually from the easiest to the next level, and must be trained for each level. Daily basis labor must meet the needed skill before starting to work. To increase workers’ motivation, companies can hold regular meetings and implement a bonus system.

3.4.2. Methods. Another category of causes was methods of work, which was lacking. This includes GMP/SSOP and machine operation. GMP/SSOP is a prerequisite program for Hazard Analysis and Critical Control Points (HACCP) and should have clear instructions. Freezers are sensitive to ambient temperature, and incorrect operation, such as opening doors too often, can affect their performance resulting in incomplete freezing. This will in turn lead to inferior quality of the frozen fish. Lack of clear procedures and instructions is an obstacle for all employees including those who handle fish and operate the freezers. Therefore, it is necessary to have clear instructions and procedures in the workplace, and to make them available at all times, while employees must understand them. Each employee should know how to perform their tasks in correct manners. It is important to make sure they know that fish is a highly perishable food, and that mishandling can cause damage quickly.

3.4.3. Machines. It was observed that machinery and equipment, including utensils, were not in good condition. Having the right weight was paramount when receiving fish, however this was often overlooked by companies, resulting in fish not meeting the required weight. Scales that were not tared were parts of the reasons, in addition to the carelessness of the workers. Knives and fish scales remover that were not sharp, corroded in some parts and not properly cleaned and sanitized have
exacerbated problems that lead to poor quality fish. The air blast freezers (ABF) were sometimes not in the right working condition which was indicated by the wrong temperature. It is recommended that scales are always tared before use, while knives and fish scalers are replaced with the new ones and should be cleaned and sanitized. Regular service and repair of the ABFs need to be done to get the temperature right.

3.4.4. Environment. Cold chain systems are mandatory for fish handling, and according to our observations, sometimes companies did not implement such systems. This was mainly due to insufficient ice and water, fluctuations in room temperature, as well as non-compliance of workers with SOPs; the latter including improper cleaning and sanitizing practices of premises. Because the doors were opened frequently, it is recommended that the processing room be arranged in such a way that the dressing table is not too close to the entrance or door to the fish solid waste disposal area. The supervisor must ensure that the SSOP is in place and is implemented. Inspections by QC should be carried out more frequently. ABF must be cleaned regularly to ensure a smooth freezing process. Deep cleaning of ABF and other machines can be done once a year or two.

4. Conclusions
This study has shown that there were 4 defects in the processing of frozen emperor fish steak at PT X, located in North Jakarta. The defects were under size fish, soft meat, off odor, and green meat, accounting for 16.4% of the total processed fish. Defects 2, 3 and 4 were indicators of quality deterioration. The chance of defect in one million is 40,739 with a Sigma level of 3.24, far below the ideal level of 6. Based on the fishbone analysis, it was revealed that the causes of defects were attributed to man (humans), methods, machines and the environment. Recommendations for improvements were suggested based on the causes, which basically focused on humans and factors that led to deterioration.

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