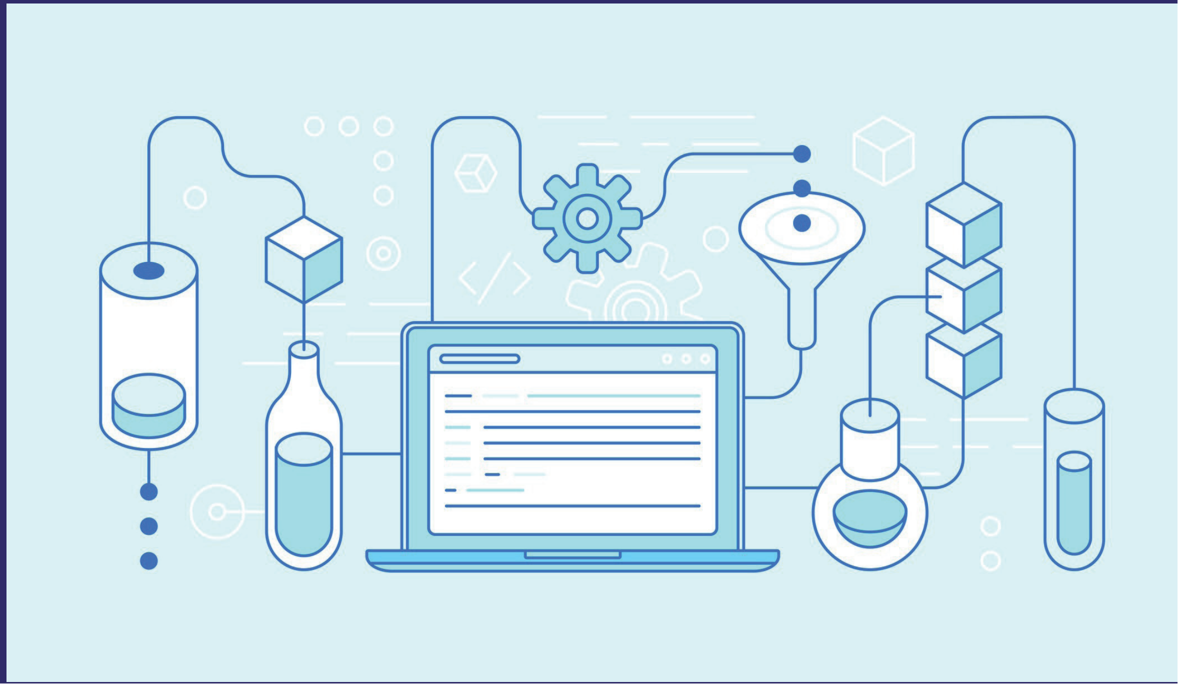
Food processing is a very important worldwide issue. Processing may have either beneficial or detrimental effects on these different properties of food. Food safety itself encompasses a whole series of processes and activities both within and outside the food processing plant that will ensure the food is free of potential chemical, physical, and biological hazards. In contrast, there are many cases deal with violation objectives of quality control, especially in the case of protecting customers from the dangers of contaminated food. This book attempts to apply Failure Mode Effects and Criticality Analysis (FMECA) methodology in an oil company. The FMECA method is applied to improve the safety of a production system, specifically the production process in the Indonesian oil company. The final measured result is the Criticality Priority Number (CPN), which refers to the severity category of the failure mode and the probability of occurrence of the same failure mode. The recommended actions proposed by the FMECA significantly reduce the CPN compared with the value before improvement, with increases of 48.33% and 38.46%, for the coconut oil and palm oil case studies, respectively.



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An Analysis for Providing Safety in the Cooking Oil Production Process through FMECA Approach

Author: **Benedictus Rahardjo**

Abstract

This study attempts to apply Failure Mode Effects and Criticality Analysis (FMECA) to improve the safety of production system, especially on the production process of an oil company in Indonesia. Since food processing is a worldwide issue and the self-management of a food company is more important than relying on government regulations, so the purpose of this study is to identify and analyze the criticality of potential failure mode on the production process, then take corrective actions to minimize the probability of making the same failure mode and re-analyze its criticality. This corrective actions are compared with the before improvement condition by testing the significance of the difference between before and after improvement using two sample t-test. Final result that had been measured is Criticality Priority Number (CPN), which refers to severity category and probability of making the same failure mode. Recommended actions that proposed on the part of FMECA give less CPN significantly compare with before improvement, with increment by 48.33% and 38.46%, respectively on coconut oil and palm oil case studies.

Keywords: Failure Mode Effects and Criticality Analysis (FMECA), Criticality Priority Number (CPN), severity and occurrence classification, coconut oil and palm oil

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Taipei, July 2015

Best regards,

Benedictus Rahardjo

Department of Industrial Management

National Taiwan University of Science and Technology

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Chapter 1
Introduction

1.1 Research background

Food processing is a very important worldwide issue. Processing may have either beneficial or detrimental effects on these different properties of food, so each of these factors must be taken into account in the design and preparation of complementary foods. Food quality is frequently associated with food safety. Food safety encompasses a whole series of processes and activities both within and outside the food processing plant that will ensure the food is free of potential chemical, physical, and biological hazards. Quality within a food processing plant may also be related to the notion of quality control. In this regard, quality control has many objectives within a food processing plants, mainly being to maintain the nutritional value of the processed product, to protect customers from the dangers of contaminated food and associated food borne diseases, and to ensure that all food laws and regulations are met.

In contrast, there are many cases deal with violation objectives of quality control, especially in the case of protecting customers from the dangers of contaminated food. One of recently case is Taiwan leaves food quality control up to the manufacturers, with the government carrying out random checks. It moved to bolster the system through amendments to the Governing Food Sanitation Act, made in June, which lay out more severe fines for willful violations of the law. Asia News on October, 26th 2013 posted news about Taiwan is facing another food scandal involving edible oils (Yage, 2013). The government fines two cooking oil companies for selling adulterated olive oil, labeled it as 'extra-virgin olive oil' or '100 percent olive oil', but in fact, they had mixed olive oil with the cheaper cottonseed variety, and to give the product a green coloring, it adds a controlled coloring agent, copper complex of chlorophyllin. Adulterated edible oils have become a problem. The latest cooking oil scare involves a popular brand that has been a major supplier to restaurants and school kitchens. In some cases, a number of products, supposedly made with peanut and chili oil, have come under the scrutiny of the authorities because they contained neither peanut nor chili oil. In one case involving olive oil, what was labeled 'completely' natural olive oil had in fact an additive. Actually, the government has two systems of certification for food: the Good Manufacturing Practice (GMP) and Certified Agricultural Standards (CAS). Consumers may not understand why there are two different certification systems. They only trust that both of them guarantee quality food, but they are wrong again. The cooking oil firm obtained GMP for its problematic products. In the wake of the cooking oil scare, some lawmakers are beginning to question the reliability of GMP and demanding the certification system be scrapped. Scrapping an unreliable certification system seems a natural thing to do under such circumstances.

Incidents involving how edible oil companies label their products have damaged trust in entire industry trying to rebuild its reputation. Regarding to Taiwan's olive oil case, South China Morning Post on November, 05th 2013 reported that more than 3,000 consumers have applied to join a class-action lawsuit over the adulterated products (Chung, 2013). One way the government tries to act out that authorities have also called on the public to play a role, reminding them they are entitled to 5 percent of any fine levied against the company they flag for concern. Actually, not only government had played a role in this case, but some food sanitation experts also gave some comments that government's efforts were not enough. They thought that if government only relied on the law they have made without further direct inspection on the production floor, it will give more chances for company to make production against the government's law (Chung, 2013). Obtaining certification such GMP or CAS, may not be difficult for food vendors, but the government has been short of resources to make sure that these vendors continue to provide quality products after obtaining certification. In addition to increasing the number of food inspectors from the current 784, they suggest the government continually review and update inspection techniques to counter any loopholes that may arise. The government should set up a food supply source data bank system that can connect with the world and help authorities trace the origins and sources of the food in question. Another source The China Post on October, 25^{th} 2013 reported that consumers usually believe that brand name vendors, or major suppliers, can be trusted. But time and time again, it has been proven that the government is unable to defend consumers.

1.2 Research objectives

The objectives of this study are described as follows.

(1) Identify and analyze the criticality of potential failure mode on a system, especially on the production process of coconut cooking oil and palm cooking oil.
(2) Take corrective actions to minimize the probability of making the same failure mode and analyze its criticality.
(3) Compare and test the significance of the difference between before and after improvement.

The final result leads to criticality priority number, which contains severity category and probability of failure mode occurrence. All the objectives of this study are met through an application of industrial engineering tool called Failure Mode Effects and Criticality Analysis.

1.3 Research scopes and constraints

Regarding to the background of this study which is a case related to an oil company, so the whole discussion is also focused on the same subject, that is an oil company. Nevertheless, the tool that used to meet the research objective can be utilized not only for oil company case study, but also it can be used for all kinds of case study as a problem-solving tool.

This study has a constraint. Because of the object of this study is an oil company in Indonesia and there is not much time to implement the proposed improvement, so the result of the proposed improvement is shown only in qualitative approach, instead of quantitative approach. Although in qualitative approach, it may still be measured with score conversion, in purpose to understand how significance the improvement can solve the problem and compare with the condition before improvement.

1.4 Thesis organization

This study consists of several steps. The first step is the general introduction, regarding to this current research. It includes background, objectives, scopes and constraints, and content organization of this research. Second step is literature review. In this step, some related theories and methods that will be used in this study will be presented. The concept of traceability system, failure mode effects and criticality analysis and its related findings will be discussed in detail. There is also an example to present the application of failure mode effects and criticality analysis clearly. In the third step, the methodology of this research will be explained. It starts from observing production process of making coconut and palm oil until build failure mode effects and criticality analysis as the main result, and graph criticality matrix for easily understandable. In the fourth step, case study from an oil company in Indonesia will be utilized for facing the real world problem. The idea for analyzing case study follow the methods that already described in the previous step of this research. Then, in the last step, the conclusion of this study will be presented. Also, there are some recommendations that can be considered as future research. Figure 1 depicts thesis organization, starts from introduction to conclusions and future research.

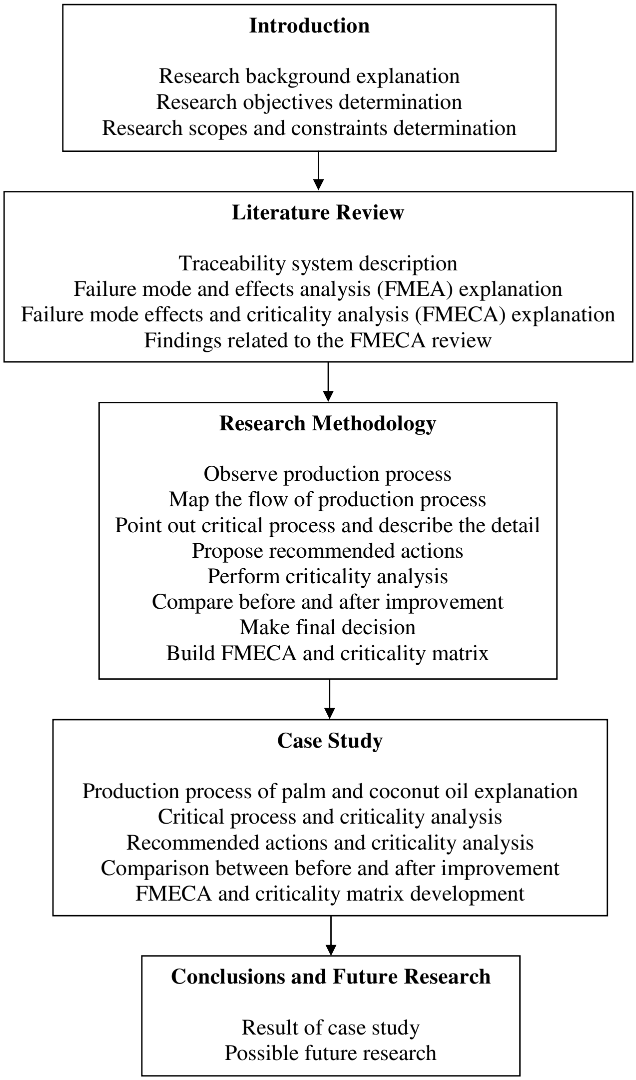

Figure 1. Thesis organization

Chapter 2

Literature Review

Quality assessment of processed food has become an emerging issue in the present era. The quality factor has broadened and covers all the aspects which satisfy consumer expectations. The terms “food quality” and “food safety” mean different things to different people. Quality has a vast number of meanings and can encompass parameters as diverse as organoleptic characteristic, physical and functional properties, nutrient content, and consumer protection from fraud. Safety is more straightforward, relating to the content of various chemical and microbiological elements in food. Clearly, food quality and safety issues need to be addressed along the entire food chain. Food and Agriculture Organization (FAO) has adopted this approach, defined as recognition that the responsibility for the supply of food that is safe, healthy, and nutritious is shared by all involved from primary production to final preparation and consumption. Compositional changes, for better or for worse, can be introduced at each and every link in the food chain.

Food safety is the responsibility of everyone involved with the food chain from regulators to producers to consumers. Traditional food safety systems are unable to detect and resolve many current problems, and to be effectively deal with the full range of complex, persistent pervasive, and evolving challenges confronting different parts of the food chain. A modern food safety system, with the new risk analysis approach has the ability to much sharper diagnose the problems and also to suggest focused interventions to properly deal with them.

A number of developing countries are already taking steps to improve and strengthen their systems for food safety management. Several are moving away from the traditional approach focused on end-product control toward a process and science-based approach. Malik, Masood, & Ahmad (2014) provide one example of science-based activities is using of risk assessment to support food safety regulations. A science-based approach enhances the ability of food safety regulators to estimate the likelihood and magnitude of the resulting risks and impact on human health. Risk analysis is just one part of an effective food safety system. Increasing public awareness of food safety hazards, concern over threats to health attributable to food hazards, and reduced confidence in the ability current food supply systems to manage food safety risks are additional factors to be considered in the development of a food chain strategy.

2.1 Traceability

Traceability is the ability to trace the history, application or location of an entity, by means of recorded identifications. Traceability is required to recall what has already occurred. Traceability system means product identification and tracking the production flow process, works backwards. The term traceability can be used in four distinct contexts: product, data, calibration, also IT and programming. Based on European Standard (1995), product context may relate materials, their origin, processing history, and their distribution and location after delivery. In data context, it relates calculations and data generated throughout the quality looping, sometimes back to the requirements for quality. In calibration context, it relates measuring equipment to national or international standards, primary standards, basic physical constants or properties, or reference materials. Ramesh, Dwiggins, De Vries, & Edwards (1995) explained that traceability relates design and implementation back to the requirements for a system in IT and programming context. Then, Moe (1998) stated there are two kinds of traceability, internal traceability and chain traceability.

Internal traceability tracks internally in one of the steps in the chain, for example the production step. Internal traceability is suitable for pure batch processing, being able to trace the raw material that went into a final product, and its application is in the most of food manufacturers. However, for continuous or semi-continuous processing can be very difficult to establish internal traceability. Moe (1998) showed that a good system for internal quality control and traceability of a production process can yield several competitive advantages such as:

- Allows for improving process control.
- Cause-and-effect indications when product does not conform to standards.
- Allows for correlating product data with raw material characteristics and processing data.
- Better planning to optimize the use of raw material for each product type.
- Builds trust and confidence in affected products, businesses or systems.
- Carries out an easier quality auditing process.

Chain traceability tracks all of the steps in the chain, from harvest through transport, storage, processing, distribution, and sales, where full traceability is required. In principle, this kind of traceability allows either information is stored locally in each of the steps in the chain sending only product identification information along with the product, or information follows the product all the way through the chain. If the information follows the product, it is very useful whenever bring information from early steps in the chain to the consumer or to advertise and market special features of a product. In practice, most information is stored locally and little follows the product. An example of full chain traceability in a complicated chain with many steps is seen in the Danish pork industry, provided by Anon (1996). Many advantages can accrue from establishing chain traceability:

- Establishes the basis for efficient recall procedures to minimize losses.
- Information about the raw material can be used for better quality and process control.
- Avoids unnecessary repetition of measurements in two or more successive steps.
- Improves incentive for maintaining inherent quality of raw materials.
- Makes possible the marketing of special raw material or product features.

2.2 Failure mode and effects analysis

Failure Mode and Effects Analysis (FMEA) was one of the first systematic techniques for failure analysis. This technique was developed to study problems that might arise from malfunctions of systems. It involves reviewing as many components, assemblies, and subsystems as possible to identify failure modes, and their causes and effects. A few different types of FMEA analysis exist, such as functional, design, and process FMEA. Functional FMEA is a tool that allows a team to systematically identify, document, and prioritize potential functional failure modes, their effects and causes. Design FMEA is used to uncover design risk, which includes possible failure, degradation of performance and potential hazards. Process FMEA is often developed at the time when a new product or process is being introduced. The following example on Table 1 shows about the application of general FMEA in system receiver case study, taken from US MIL-STD-1629A.

Sometimes FMEA is extended to FMECA to indicate that criticality analysis is performed too. The FMEA can be accomplished without a Criticality Analysis (CA), but a CA requires that the FMEA has previously identified system level critical failures. When both steps are done, the total process is called a FMECA.

Table 1. Example application of general FMEA in system receiver case study (US MIL-STD-1629A, 1983)

ID number	Item/functional identification	Function	Failure modes and causes	Failure effects			Failure detection method
				Local effects	**Next higher level**	**End effects**	
001	Antenna Output	Conducts Transmitted Signal	No Reception	Antenna Cannot Receive Incoming Trans	Loss of Signal to Receiver	System Disabled Loss of Communication with Tower	Bite Sounds Alarm
002			Signal Leakage	Antenna Not Receiving Proper Signal	Incorrect or Incomplete Signal to Receiver	System Degraded Poor Reception	None
003			Spurious Reception	Intermittent Signal Reception	Incomplete Signal to Receiver	System Degraded Poor Reception	None
004	RF Amplifier Output	Amplifies RF Signals from Antenna	No Output	Loss of Antenna Signal	No Signal to Mixer	System Disabled Loss of Communication with Tower	Bite Sounds Alarm

2.3 Failure mode effects and criticality analysis

An industrial engineering tool called Failure Mode Effects and Criticality Analysis (FMECA) is a visibility tool that can easily be understood and used to detect the possible critical points (failures) of its traceability system. It is useful in design comparison. FMECA is characterized by a bottom-up approach. It breaks down any system (product and/or production process) into its fundamental components to detect all potential failure modes and their effects. Major benefits derived from a properly implemented FMECA effort are as follows (Muralidharan, 2015):

- It provides a documented method for selecting a design with a high probability of successful operation and safety.
- A documented uniform method of assessing potential failure mechanisms, failure modes and their impact on system operation, resulting in a list of failure modes ranked according to the seriousness of their system impact and likelihood of occurrence.
- Early identification of Single Failure Points (SFPS) and system interface problems, which may be critical to mission success and/or safety. They also provide a method of verifying that switching between redundant elements is not jeopardized by postulated single failures. This is the most important benefits of the FMECA regarding with input to the troubleshooting procedure and locating of performance monitoring/fault detection devices.
- An effective method for evaluating the effect of proposed changes to the design and/or operational procedures on mission success and safety.
- A basis for in-flight troubleshooting procedures and for locating performance monitoring and fault-detection devices.
- Criteria for early planning of tests.

FMECA involves two sub-analysis, they are Failure Mode and Effects Analysis (FMEA) and Criticality Analysis (CA). FMEA analysis is used to identify the main causes for effectiveness or efficiency loss. CA is the tool that can be used to improve reliability and manage failures based on risk instead of perception. Criticality analysis can be used for more than just ranking each failure. By identifying the characteristics that make each failure critical, the analysis will also provide valuable information to decide what actions will reduce risk for all failures. There is much information that can get from FMECA (Bertolini, Bevilacqua, & Massini, 2006):

- The subsystems and final items of the system in a hierarchical arrangement.
- Any failure or generic malfunctioning, with a list and description of all potential failure modes for the process/product being analyzed.
- The probability, severity, and detection ability of each failure mode's occurrence.
- The criticality analysis, which ranks all failure modes in order of importance.

The criticality assessment, to assess the risk, involved in each failure mode previously recognized in FMEA analysis, has been performed by either developing a Risk Priority Number (RPN), or calculating an item criticality number. The RPN method is preferred mostly by the manufacturing industries such as automotive companies (Ford, 1988), domestic appliance firms (Zanussi, 1989), and tire companies (Pirelli, 1988). There are two approaches of using the RPN method, in quantitative (number) and qualitative (code) manner. RPN method with quantitative approach is only based on three factors: occurrence, severity, and detection. Each factor uses ranking method, start from rank 1 through 10, which rank 1 means almost no effect is happened and rank 10 means the most effect can be seen clearly. Finally, our focus is located on the highest risk priority number, obtained by multiplying the rank from three factors, resulting RPN ranges from 1 to 1000. Other manner of using the RPN method is qualitative approach, that utilizing code instead of number, such in quantitative approach. For example as stated in US MIL-STD-1629A, in severity classification, there are four categories (I through IV), which category I indicates catastrophic and category IV indicates minor severity. Also, same with probability of occurrence categories, denoted by level A (frequent) through level E (improbable). The failure mode may then be charted on a criticality matrix using severity code as one axis and probability level code as the other.

Some drawbacks can be found of using the RPN method. It is based on a simple multiplication of the factors' scores is a debatable method. For example, it is not certain that all designers in every situation want to assign the same importance (weight) to each criterion. This situation may come up related with subjective assessment. The detection ranking in the RPN approach should be dropped (Bowles, 2004), because it is misleading, which the ranking is a measure of whether subsequent testing will show the failure mode exists rather than whether the failure will be detected when it occurs.

Criticality number technique is used mostly in the chemical industries or some other daily product companies (Braglia, 2000). The criticality number calculation is described in US MIL-STD-1629A: Procedures for performing a failure mode, effects and criticality analysis. The procedure consists of determining the failure-effect probability (β), the failure mode ratio (α), the part failure rate (λ_p), and its operating time (t), and using these values to compute a failure mode Criticality Number (CN) for each item failure mode *i* as:

$$CN_i = \alpha_i \times \beta_i \times \lambda_p \times t$$

The part failure rate (λ_p) is a numerical representation of the number of expected failures for a given item over a specified period of time. This may be a predicted or estimated value and is commonly expressed in failures per million hours. It is usually fed into the FMECA from a failure rate prediction based on a model. The failure mode ratio (α) is the probability, expressed as a decimal fraction, that given part or item will fail in the identified mode. Failure mode ratio may be taken from a database source such as Failure Mode/Mechanism Distributions (FMD-91) authored by Chandler, Denson, Rossi, & Wanner (1991), shown on Table 2. The failure-effect probability (β) is a numeric value representing the conditional probability that the failure effect will result in the identified criticality classification, given that the failure mode occurs. It represents the analyst's best judgment as to the likelihood that the loss will occur. Operating time (t) is the total operating time that the indicated item is expected to function during the mission scenario. The value of operating time commonly used is the total life cycle of the equipment. Criticality Number (CN) or failure mode criticality is a relative measure of consequence of a failure mode and its frequency of occurrence. All of the factors are not applicable to qualitative analysis. For graphical analysis, a criticality matrix may be charted using CN on one axis and severity code on the other. The following example on Table 3 shows about the application of severity classification and criticality number in security system regulator case study, taken from US MIL-STD-1629A (Alion System Reliability Center, 1983).

Table 2. Part failure mode distributions (Chandler, Denson, Rossi, & Wanner, 1991)

Device type	**Failure mode**	**Failure mode probability (α)**
Diode, Rectifier	Short	0.51
	Open	0.29
	Parameter Change	0.20
Resistor, Fixed, Film	Open	0.59
	Parameter Change	0.36
	Short	0.05

Table 3. Example application of severity classification and criticality number in security system regulator case study (US MIL-STD-1629A, 1983)

ID number	**Item/functional identification**	**Function**	**Failure modes and causes**	**Severity class**	**Failure effect probability (β)**	**Failure mode ratio (α)**	**Part failure rate (λ_p)**	**Operating time (t)**	**Criticality Number (CN)**
001	CR3 Rectifier Diode	Half-Wave Rectifier	Short	I	1	0.51	0.123×10^{-6}	43,800	2.747×10^{-3}
002			Open	I	1	0.29	0.123×10^{-6}	43,800	1.562×10^{-3}
003			Parameter Change	IV	1	0.20	0.123×10^{-6}	43,800	1.077×10^{-3}
004	R1 Resistor Fixed Film 100 Ohms	Current Limit	Open	I	1	0.59	0.004×10^{-6}	43,800	0.103×10^{-3}
005			Short	III	1	0.05	0.004×10^{-6}	43,800	0.009×10^{-3}
006			Parameter Change	IV	1	0.36	0.004×10^{-6}	43,800	0.063×10^{-3}

The output of FMECA is identifying weakness in the system design, focusing attention on a few components rather than on many, which can be seen through the failure mode that has biggest value of critical points. Next step of course, to propose some improvements, whether it may come from management (new procedures) or structural (plant modifications) change. The purpose is to minimize the possibility of failure's occurrence and even make zero possible critical points occurs.

There are some findings related with FMECA. Bertolini, Bevilacqua, & Massini (2006) points out on application in the pasta production plant. The results obtained through the application of the method proposed to the specific case study of a durum wheat pasta production process demonstrate that FMECA application to the analysis of the internal traceability system for food processing companies can grant valuable results. The well-known industrial engineering tool, owing to its ease of use and lack of, can be efficiently used to analyze, improve and, if necessary, re-engineer a food product's internal traceability system. Braglia (2000) noted that if reliable quantitative judgments are available for some criteria, they can easily be included in Analytic Hierarchy Process (AHP) analysis. This possibility means that Multi-attribute Failure Mode Analysis (MAFMA) can also eventually easily replace or integrate in a more complete manner FMECA studies already executed by maintenance staff.

The extension of FMECA using fuzzy logic is performed by Bowles & Pelaez (1995a). Fuzzy logic provides a tool that can be used throughout the design process for performing a criticality analysis on a system design and prioritizing the failures identified in a FMECA for corrective actions. The result allows appropriate actions to correct or mitigate the effects of a failure to be prioritized even though the information available is vague, ambiguous, qualitative or imprecise. Bowles (2004) also gave some criticisms of using the RPN methodology. The fundamental problem is that ordinal scales are used to rank the failure modes in terms of severity, occurrence, and detection, but the scales are treated as if numerical operations on them, most notably multiplication, are meaningful. The results are not only meaningless but are, in fact, misleading. Bowles recommended if a cost could be associated with each failure effect, failures could be placed on a dollar scale (a ratio scale). Multiplying the cost of the failure effect and the probability of occurrence of the underlying failure mode could produce an “expected cost” of the failure. Finally, proposed design changes could then be evaluated by their effect on the expected cost. The summary results and some comments for each finding are shown on Table 4.

Table 4. Some findings related with FMECA

Title (author, year)	Results	Comments
FMECA approach to product traceability in the food industry (Bertolini, Bevilacqua, & Massini, 2006)	Internal traceability system for a durum wheat pasta production process. FMECA analysis in qualitative approach (using only severity and occurrence classification).	Only focus on the production process, not all of the steps in the chain. Subjective judgment: may come up with different appraisal by each appraiser.
MAFMA: multi-attribute failure mode analysis (Braglia, 2000)	Integrates four different factors: chance of failure, chance of non-detection, severity, and expected cost. Analytic Hierarchy Process (AHP) technique is adopted. Evaluated through the use of a series of pair wise judgments.	The different factors should be considered jointly and not in parallel. It's not easy to quantify the failure factors included to the final failure cost (e.g. public opinion damage: intangible).
Fuzzy logic prioritization of failures in a system failure mode, effects and criticality analysis (Bowles & Pelaez, 1995a)	Prioritizing failures for corrective actions based on fuzzy logic.	Handled in a consistent manner, even though the information is vague, ambiguous, qualitative, or imprecise.

Table 4. Some findings related with FMECA (cont'd)

Title (author, year)	**Results**	**Comments**
Fuzzy logic prioritization of failures in a system failure mode, effects and criticality analysis (Bowles & Pelaez, 1995a)	Evaluate the risk using the linguistic terms that are employed in making the criticality assessment.	More flexible structure for combining the severity, occurrence, and detect ability parameters. Doubt in actual applicability in consideration of the difficulties in defining the (numerous) rules and membership functions required.
An assessment of RPN prioritization in a failure modes effects and criticality analysis (Bowles, 2004)	Use of ordinal ranking numbers as numeric quantities.	Lack of continuity in the RPN measurement scale, although it is an integer scale.
	Problem: duplicate RPN values with extremely different characteristics.	It's not certain that all designers in every situation want to assign the same importance to each criterion (variation).
	Problem: varying sensitivity to small changes.	RPN number offers no clue as to how the design can be improved or which number need to change to have meaningful improvement.
	The detection ranking should be dropped, because it's misleading.	Replaced detection ranking with test might be needed to more accurately determine the frequency of occurrence of the potential failure.

Chapter 3

Research Methodology

The research framework of this study is illustrated on the following Figure 2.

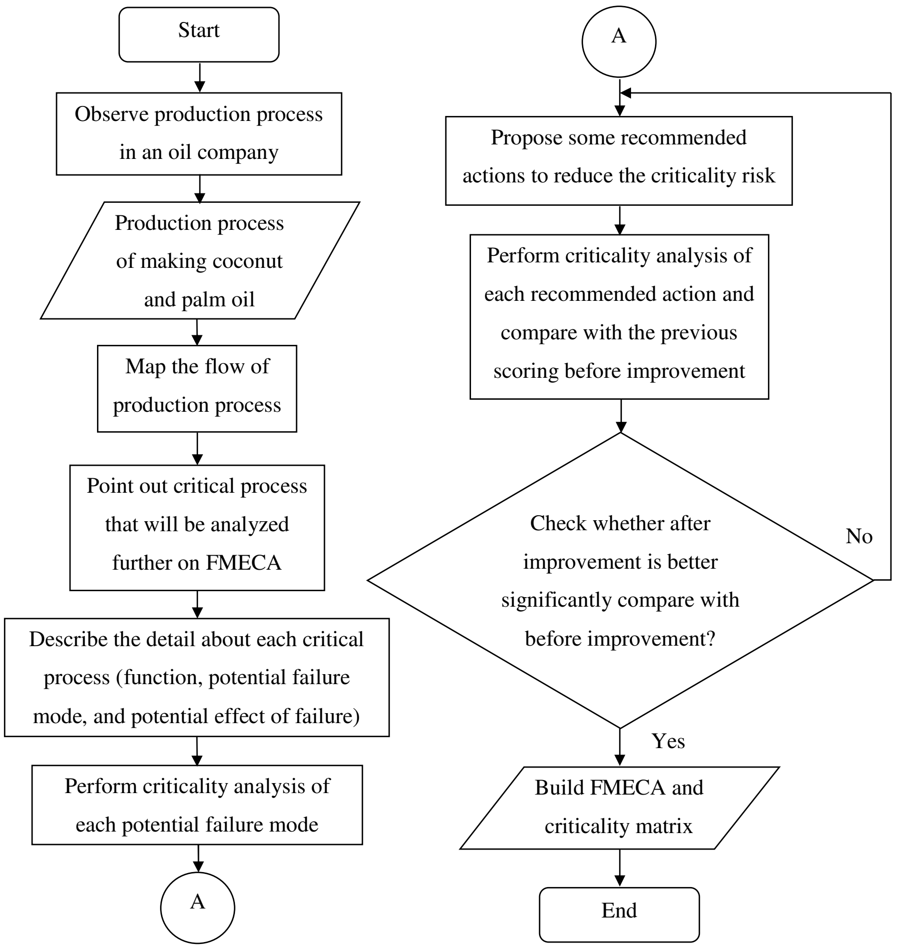

Figure 2. Research framework

This study is focused on the application of an industrial engineering tool called Failure Mode Effects and Criticality Analysis (FMECA) in the Indonesian oil company. The oil company named XYZ produces palm and coconut oil as their main product. The first activity is observing production process inside the oil company, which is used as the input of this study. After observing the production process, then mapping it on the schematic diagram to know the flow of production process in making palm and coconut oil.

Then, point out some critical processes which will be analyzed further on FMECA. Critical process can be determined by observing the process directly and doing consultation with process engineer at XYZ oil company. Each critical process will be described with the following information as detail as possible:

- Function: a concise statement regarding the process's function.
- Potential failure mode: the way in which a failure is observed, describes the way the failure occurs, and its impact on equipment operation. The potential failure modes are determined by examining process outputs. This information will be treated as the main point of FMECA to be analyzed specifically, so that it will be given an identification number (ID) to distinguish each potential failure mode.
- Potential effect of failure: the consequence a failure mode has upon the operation, function or status of a system or equipment.

The next step is performing criticality analysis of each potential failure mode. There are two approaches to perform criticality analysis, in quantitative and qualitative approach. In quantitative approach, criticality analysis consists of four factor, they are failure effect probability, failure mode ratio, failure rate, and operating time. In this study, operating time is set from observation, which is 8 hours within a day. Failure rate is determined by how many number of failures had done within 8 hours. A kind of failure can be waste or defective products. The value of failure mode ratio is taken from Failure Mode/Mechanism Distributions (FMD-91) as a standard to utilize the ratio in

Table 5. Normalized failure mode distributions for FMECA, FMD-91 (Chandler, Denson, Rossi, & Wanner, 1991)

Device type	Failure mode	Failure mode ratio
Chopper	Contact failure	0.48
	Short	0.25
	Open	0.25
	Coil failure	0.02
Mechanical filter	Leaking	0.67
	Clogged	0.33
Sensor	Erratic output	0.59
	Short	0.20
	Open	0.12
	No output	0.10

this study. Table 5 shows some devices that used on coconut and palm oil case study, its failure mode and failure mode ratio. All failure mode ratio may be utilized directly or must be justified regarding to some processes because of inexactly same as the application of FMD-91. The multiplication four factors become a new value called criticality number for each failure mode.

Besides performing criticality analysis in quantitative approach, this study also performs in qualitative approach. In qualitative approach, there are two factors which are going to be considered, severity and occurrence. In terms of severity, there are four categories and each category has different description that will be used as reference in this study. The basic principle of severity classification is adopted from US MIL-STD-1629A (Alion System Reliability Center, 1983). Table 6 shows the four categories of severity and each description, regarding to the case at XYZ oil company.

Table 6. Severity classification and description

Category	Description	Definition
I	Catastrophic	A failure which may cause total loss of product (threaten the human's life)
II	Critical	A failure which may cause severe inefficiency and/or ineffectiveness in the reconstruction of product (change the taste, decrease shelf life)
III	Marginal	A failure which may cause minor inefficiency and/or ineffectiveness in the reconstruction of product (reprocess)
IV	Minor	A failure which may be overcome with an unscheduled measure

In terms of occurrence, there are five categories and each category has different description that will be used as reference in this study. The basic principle of occurrence classification is adopted from US MIL-STD-1629A (Alion System Reliability Center, 1983). Table 7 shows the five categories of occurrence and each description, regarding to the case at XYZ oil company.

Table 7. Occurrence classification and description

Category	Description	Definition
A	Frequent	A high probability of occurrence (equal or greater than 0.03 of the overall probability of failure)
B	Reasonably common	A moderate probability of occurrence (more than 0.005, but less than 0.03)
C	Occasional	An infrequency probability of occurrence (more than 0.0005, but less than 0.005)
D	Rare	An unlikely probability of occurrence (more than 0.00005, but less than 0.0005)
E	Extremely rare	A failure whose probability of occurrence is essentially zero (less than 0.00005)

Table 8. Conversion from qualitative analysis to quantitative analysis for severity classification

Category	Description	Conversion
I	Catastrophic	4
II	Critical	3
III	Marginal	2
IV	Minor	1

Table 9. Conversion from qualitative analysis to quantitative analysis for occurrence classification

Category	Description	Conversion
A	Frequent	5
B	Reasonably common	4
C	Occasional	3
D	Rare	2
E	Extremely rare	1

In purpose to measure the criticality in qualitative analysis, so each category is converted to be quantitative analysis, which is ease to be measured. The conversion from qualitative analysis to quantitative analysis for severity and occurrence are shown on Table 8 and Table 9, respectively.

Table 8 and Table 9 show that larger score indicates greater severity and probability of occurrence. Final scoring is obtained by taking average on severity and occurrence factor. The score itself called Criticality Priority Number (CPN). After performing the calculation of CPN for each potential failure mode, then rank it from the highest to the lowest value, to determine which potential failure mode must be prioritized first to focus and handle on it. The ranking of each potential failure mode is used for prioritizing to propose some recommended actions, start from the most important to be noticed until the least important one. The purpose of proposing some recommended actions is to give improvement on the system, so that can minimize the probability of making the same failure mode, and of course by calculation on FMECA, it may reduce the criticality risk. All of recommended actions are measured in qualitative analysis on the same way such the condition before improvement. By using quantitative analysis, it becomes easier to compare the condition before and after improvement. Comparison of the two scorings is then calculated and analyzed by two sample t-test, because the number of potential failure mode as the subject of this study is not too many, less than 30, and two sample t-test is suitable for testing that condition. Regarding to the utilization of two sample t-test, it's important to check the normality assumption, also doing test for equal variances as the requirements before using two sample t-test. After that, check whether after improvement is better significantly or not compare with before improvement by comparing P-value obtained from two sample t-test with alpha (α) risk set in 5%. If it's so, continue to the next step is build the FMECA and criticality matrix. Otherwise, the recommended actions don't change the system to be better, so it must find another action and re-evaluate through the criticality analysis and doing comparison. FMECA consists of all of the information that already describe on the previous steps, start from critical process with each detail description and criticality analysis, until the recommended actions and their calculation for severity and occurrence. Once FMECA is already built, the following step is making criticality matrix, which map for the ID of each potential failure mode. Criticality matrix consists of two factors that are considered on FMECA, severity and occurrence, so that the shifted position depicts the condition before and after improvement as final result.

Chapter 4

Case Study

4.1 Production process of coconut and palm oil

All of the data in this study, including production process of palm and coconut oil and the numbers which are determined on the part criticality analysis of Failure Mode Effects and Criticality Analysis (FMECA), are obtained from direct observation on the production floor, measure it as accurate as possible, and then consult the observation result with company's process engineer.

Figure 3 depicts the flow production process of coconut oil, start with copra as raw material then goes into cutting process. In cutting process, there are two sub processes, cleaving and chopping. Cleaving is cutting the whole copra into two portions, in purpose to be easy while chopping by machine, so can get the maximum yield. The equipment used for cutting the whole copra is knife. After getting two portions of whole copra, then goes into chopping process. Chopping is grating copra flesh into small parts, with chopper used as main equipment to deal with it. Small parts of copra flesh will be added with water in purpose of getting liquid form. Pressing is a process which press copra flesh to release two kinds of product, Crude Nut Oil (CNO) as the main outcome and oil cake. An oil cake is the solids remaining after pressing copra flesh to extract the liquids. To achieve company's target that is maximizing yield, so there is an additional process taken into oil cake to extract more to get CNO. Result of extracting process on oil cake is CNO yield added and its side product called pellet. Pellet most common use is in animal feed, also it is possible to use for culinary purposes and applied to the forehead to threat headaches (Manandhar, 2002). In some regions of the world, it is used as boiler fuel as a means of reducing energy costs, for which it is quite suitable (Clay, 2004).

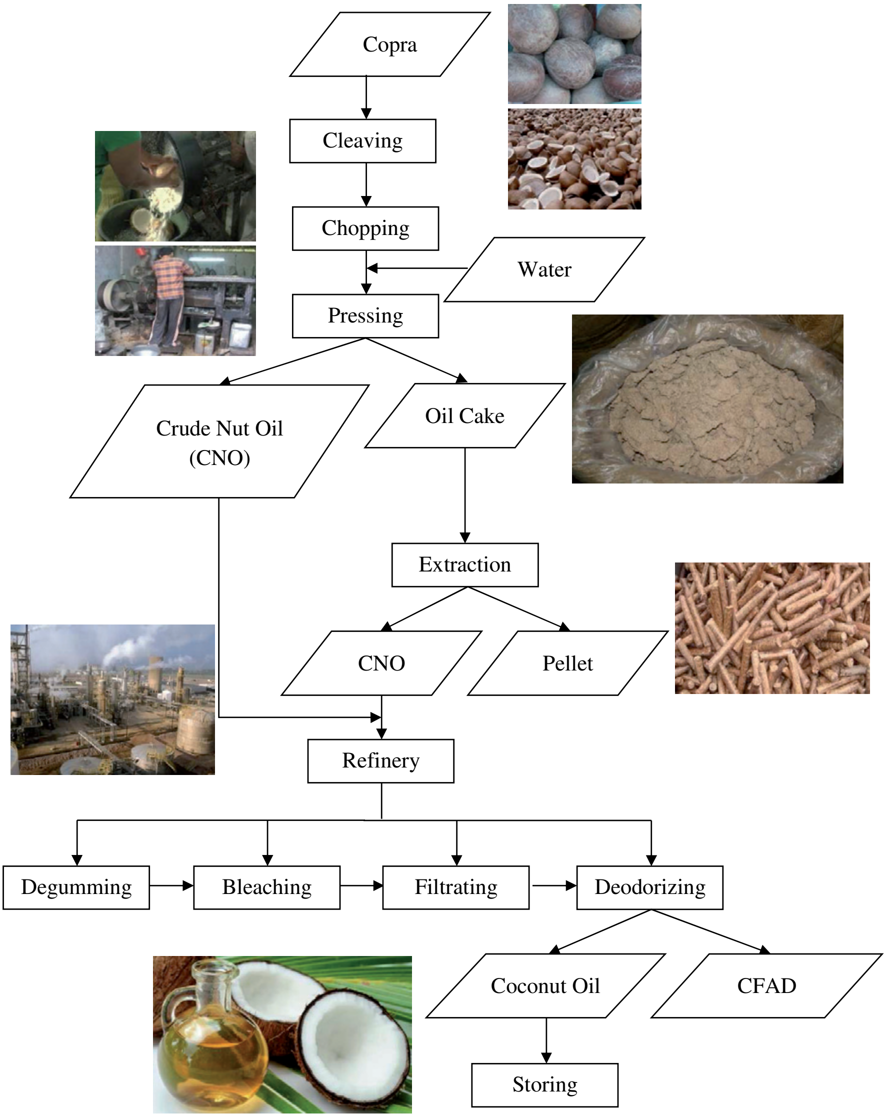

Figure 3. Flow production process of coconut oil

CNO as the main outcome from copra will treat further in refinery process become coconut oil. Refinery process consists of four sub processes: degumming, bleaching, filtrating, and deodorizing. Start from degumming process is to relieve the gum which still contain a little bit in CNO. Then, next process after degumming is bleaching. The purpose of bleaching process is to purify the oil color from brown as copra color into clear to be good looking as a coconut oil. To purify oil color, the company uses chemistry substance to change from brown color into clear. After bleaching process, the CNO goes into filtrating process, which filtrate the residue as a result of previous process. The residue will be filtrated using a mesh. Continue to the last process on refinery process is deodorizing. On this process, it relieves the oil odor and moisture levels using deodorized material fill into the mixture. There are two results of deodorizing process: coconut oil and Coconut Fatty Acid Distillate (CFAD). Coconut oil is one of main product at XYZ oil company. CFAD is a by-product of coconut cooking oil production. This oil can be used as raw material to produce soap. Coconut oil will treat into storing process, which is filling oil into the bottle, then storing it on particular place, away from light and airflow.

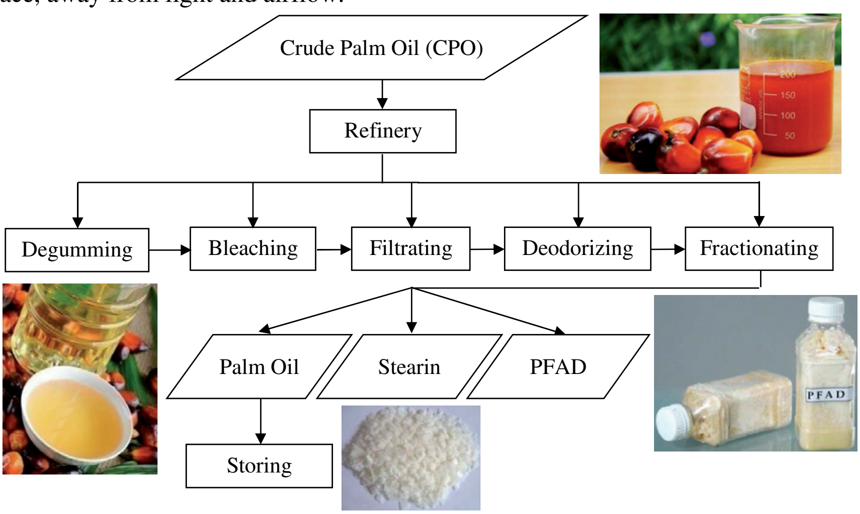

Figure 4. Flow production process of palm oil

Figure 4 depicts the flow production process of palm oil, start with Crude Palm Oil (CPO) as raw material then goes directly into refinery process. Production process of making palm oil has a little bit difference compare with making coconut oil. The first difference is there is no cutting and pressing process anymore since the raw material is directly found in liquid form. Second difference is the refinery process consists of five sub processes, instead of only four sub processes that can be found in making coconut oil. The additional sub process on refinery process, that is fractionating, will be done after deodorizing process finished. In detail, refinery process consists of degumming, bleaching, filtrating, deodorizing, and fractionating sub process.

CPO as raw material goes into degumming process, which is the first sub process on refinery process. Degumming process is relieving the gum which still contain a little bit in CPO. Then, next process after degumming is bleaching. The purpose of bleaching process is to purify the oil color from red-orange as CPO color into clear to be good looking as a palm oil. To purify oil color, the company uses chemistry substance to change from red-orange color into clear. After bleaching process, the CPO goes into filtrating process, which filtrate the residue as a result of previous process. The residue will be filtrated using a mesh. Continue to the next process on refinery process is deodorizing. On this process, it relieves the oil odor and moisture levels using deodorized material fill into the mixture. Fractionating as the additional sub process on refinery process is to separate final product between palm oil and stearin. There are three results of fractionating process: palm oil, stearin, and Palm Fatty Acid Distillate (PFAD). Palm oil is the other main product at XYZ oil company, besides coconut oil. Stearin is the solid fraction of palm oil that is produced by partial crystallization at controlled temperature. It is a useful source of natural hard vegetable fat for food applications (Lim, 2010). The difference between palm oil and stearin is palm oil is the liquid fraction, while stearin is the solid fraction. PFAD is made from refining crude palm oil. It is used for many industries such as soap industries, animal food industries, and also is used as raw materials for bio-diesel and chemical industries. Palm oil will treat into storing process, which is filling oil into the bottle, then storing it on particular place, away from light and airflow.

4.2 Critical process

4.2.1 Coconut oil

From Figure 3 that depicts the production process of coconut oil, there are many processes that copra as raw material has been treated along the production line, starts from cleaving until deodorizing through refinery process. There are some processes that had been found and detected as critical process, which the company should take notice on it. The following discussion will discuss about critical process and its description, including their function, potential failure mode, and potential effect of failure.

- Cutting process consists of two sub processes: cleaving and chopping. In cleaving process, the potential failure mode that might be happened is knife is not sharp enough to cut the whole copra, and the potential effect if the failure occurs is not all copra can be completely cut into two portions. Another potential failure that might be happened is knife is rusty, so it affects to the deterioration of oil, which lead to change taste and decrease shelf life time. Chopper as the equipment used in chopping process may have the similar potential failure effect with the knife which is used in cleaving process. Chopper might not be sharp enough to grate the copra flesh and could be rusty in a long-term use. The potential failure is not all copra flesh can be completely grated, so it decreases the yield. Rusty chopper can deteriorate the oil (change taste and decrease shelf life time), also may affect to the copra flesh's color, which lead to change the oil color into brown like rust.
- The potential failure mode that might be happened in pressing process is pressing force is not strong, so it causes CNO yield that the company want to achieve as their target can't be maximum.

- Among four sub processes on refinery process, the following three sub processes: bleaching, filtrating, and deodorizing, are indicated as potential failure might be happened on it. On bleaching process, filling up the chemistry substance into mixture is a kind of potential failure mode, which leads to inappropriate composition used. If too much chemistry substance, it will affect to the oil taste, while if too less, the oil color is still in brown as copra color and it should be reprocessed to get the appropriate color such as coconut oil in general. A failure like the mesh is already full of residue on filtrating process can be happened if there is no schedule to change it. If that condition happens, it may cause much oils are stopped on the mesh and of course, it decreases the CNO yield. Deodorized material used on deodorizing process must be in appropriate composition as well as using chemistry substance on bleaching process. Similar with bleaching process that improper composition of deodorized material may lead to the failure mode that might be happened in deodorizing process. If too much, deodorized material will be tasted in coconut oil as the final product. In contrast, if it is too less can deteriorate the oil (change taste and decrease shelf life time).
- On the storing process, one thing that should be noticed is keep away the bottle from light and airflow. The potential failure mode that might be happened is bottle places carelessly, not on the right place, so that early oxidation can be occurred. If oxidation occurs, it may decrease shelf life time.

In purpose to simplify the writing of potential failure mode on following discussion, therefore each of them will be coded as failure ID. First of all, each process is coded as function ID. Then, potential failure mode is coded as failure mode ID. Combine it together become failure ID, which mean a specific potential failure mode come from particular process. For instance, cutting process is coded as function ID 1. On cutting process, there are four potential failure modes, such as knife is not sharp enough to cut the whole copra is coded as failure mode ID 10. Combine function ID and failure mode

ID become failure ID 1.10, means knife is not sharp enough to cut the whole copra is the first potential failure mode of cutting process. Detail code of each potential failure mode can be seen on Table 10.

Table 10. Code of each potential failure mode on coconut oil case study

Process	**Potential failure mode**	**Failure ID**
Cutting	Knife is not sharp enough to cut the whole copra	1.10
	Knife is rusty	1.20
	Chopper is not sharp enough to grate the copra flesh	1.30
	Chopper is rusty	1.40
Pressing	Pressing force is not strong	2.10
Refinery	Chemistry substance is not in appropriate composition	3.10
	Mesh is already full of residue	3.20
	Deodorized material is not in appropriate composition	3.30
Storing	Bottles place carelessly	4.10

4.2.2 Palm oil

From Figure 4 that depicts the production process of palm oil, there are many processes that Crude Palm Oil (CPO) as raw material has been treated along the production line, start from degumming until fractionating, which is all of the process within a set of refinery process. The following discussion will discuss about critical process and its description that had been found and detected from observation, which the company should take notice on it. Description of each critical process includes its function, potential failure mode, and potential effect of failure.

- Among five sub processes on refinery process, the following three sub processes: bleaching, filtrating, and deodorizing, are indicated as potential failure might be happened on it. On bleaching process, filling up the chemistry substance into mixture is a kind of potential failure mode, which leads to inappropriate composition used. If too much chemistry substance, it will affect to the oil taste, while if too less, the oil color is still in red-orange as CPO color and it should be reprocessed to get the appropriate color such as palm oil in general. A failure like the mesh is already full of residue on filtrating process can be happened if there is no schedule to change it. If that condition happens, it may cause much oils are stopped on the mesh and of course, it decreases the CPO yield. Deodorized material that used on deodorizing process must be in appropriate composition as well as using chemistry substance on bleaching process. Similar with bleaching process that inappropriate composition of deodorized material may lead to the failure mode that might be happened in deodorizing process. If too much, deodorized material will be tasted in palm oil as the final product. In contrast, if it is too less can deteriorate the oil (change taste and decrease shelf life time).

- On the storing process, one thing that should be noticed is to keep away the bottle from the light and airflow. The potential failure mode that might be happened is bottle places carelessly, not on the right place, so that early oxidation can be occurred. If oxidation occurs, it may decrease shelf life time.

Utilizing the same idea as on coconut oil discussion, in purpose to simplify the writing of potential failure mode on following discussion, therefore each of them will be coded as failure ID. For instance, refinery process is coded as function ID 1. On refinery process, there are three potential failure modes, such chemistry substance is not in appropriate composition is coded as failure mode ID 10. Combine function ID and failure mode ID become failure ID 1.10, means chemistry substance is not in appropriate composition is the first potential failure mode of refinery process. Detail code of each potential failure mode can be seen on Table 11.

Table 11. Code of each potential failure mode on palm oil case study

Process	Potential failure mode	Failure ID
	Chemistry substance is not in appropriate composition	1.10
Refinery	Mesh is already full of residue	1.20
	Deodorized material is not in appropriate composition	1.30
Storing	Bottles place carelessly	2.10

4.3 Criticality analysis

After determining the critical process of making coconut and palm oil, then analyze the criticality of each potential failure. There are two approaches for analyzing criticality of potential failure, quantitative and qualitative approach. In quantitative approach, failure effect probability (β), failure mode ratio (α), failure rate (λ_p), and operating time (t) are assigned on each potential failure to get the final failure mode (C_m) by multiplying that four factors. Failure effect probability will be assigned in total value of 1 on each potential failure mode. For example, the knife which is used to cut the whole copra in cleaving process is not sharp enough will cause for sure that not all copra can be completely cut into two portions, has failure effect probability equal to 1. The knife is rusty also will cause for sure deterioration of oil that lead to change the taste and decrease shelf life time, has failure effect probability equal to 1. Similar with knife, chopper which is used to grate copra flesh into small parts in chopping process is not sharp enough will cause for sure that not all copra flesh can be completely grated, has failure effect probability equal to 1. Pressing force is not strong will cause for sure that CNO yield can't reach the maximum level of yield; mesh is already full of residue will cause for sure that much oils are stopped on the mesh; and bottles place carelessly will cause for sure that early oxidation can be occurred, all has failure effect probability equal to 1. In case of a potential failure have two potential effects, so that each potential effect will be weighted as conditional probability that the failure effect will result, given that the failure mode occurs, and sum of the weight is equal to 1. Each weight value comes from analyst's judgment based on number of complaints from customer to marketing within one year, and also observation data obtained from process engineer. For example, chopper is rusty may cause two effects. The first effect is deterioration of oil (change taste and decrease shelf life time), while the second effect is related with copra flesh's color, which can be going into brown color like rust. Based on historical data in 2013 recorded from company, that within one year, there are total 223 records, contain with 2 complaints from customer because of rusty flavor and 221 defectives from process quality data because of the oil still in brown color. According to that result of two effects, the failure effect probability assigned for first effect is 0.009, and for second effect is 0.991, as the literature states that sum of the potential failure effect must be equal to 1. Another example is on bleaching process, chemistry substance is not in appropriate composition may cause two effects, that are if it is too much will give effect to the oil taste, while if it is too less, the oil color is still in brown as copra color. There are 256 records, contain with 1 complaint from customer because of chemistry substance flavor and 255 defectives from process quality data because of the oil still in brown color. According to that result of two effects, the failure effect probability assigned for first effect is 0.004, and for second effect is 0.996. Similar with chemistry substance, on deodorizing process use deodorized material to relieve the oil odor and moisture levels, which might not in appropriate composition also may cause two effects. The first one is deterioration of oil could be occurred when if it is too less deodorized material used. The second one is deodorized material will be tasted since it adds too much to oil product. The failure effect probability for first effect is assigned 0.571. This number comes from 4 customer complaints that they can still smelt oil odor. While second effect is assigned 0.429, comes from 3 customer complaints because of deodorized substance flavor can be tasted.

Failure mode ratio has the similar scoring as failure effect probability, which is must be assigned in total value of 1, but in terms of each process, not on each potential failure mode as well as in failure effect probability. The ratio is taken from a standard called

Failure Mode/Mechanism Distributions (FMD-91) authored by Chandler, Denson, Rossi, & Wanner (1991) as already discussed on Table 5. For example, cutting process consists of two sub processes: cleaving and chopping. Cleaving itself consists of two potential failure modes, knife is not sharp enough to cut the whole copra and knife is rusty. Knife is not sharp has failure mode ratio is 0.48, while knife is rusty 0.02. That two ratio numbers come from contact failure and coil failure, respectively on chopper device in FMD-91 standard. Chopping also consists of two potential failure modes, chopper is not sharp enough to grate the copra flesh and chopper can be rusty in a long-term use. Similar with knife, chopper is not sharp has failure mode ratio is 0.48, while chopper can be rusty is 0.02. Totally, sum of the failure mode ratio from all four potential failure modes in cutting process is equal to 1. However the FMD-91 standard can't be used arbitrarily, it must be justified regarding to some processes, as example on refinery process, which consists of three sub processes: bleaching, filtrating, and deodorizing. On bleaching process, the ratio of potential failure mode chemistry substance is not in appropriate composition adopts from FMD-91 standard with sensor device and its failure mode is erratic output with failure mode ratio equal to 0.59. On filtrating process, the ratio of potential failure mode mesh is already full of residue adopts from FMD-91 standard with mechanical filter device and its failure mode is clogged with failure mode ratio equal to 0.33. The last sub process on refinery is deodorizing process, which its ratio of potential failure mode deodorized material is not in appropriate composition adopts from FMD-91 standard same as bleaching process. After making adjustment by adding all three ratios and divide it on same portions, the final ratio for chemistry substance and deodorized material is not in appropriate composition equal to 0.39, and mesh is already full of residue equal to 0.22. If there is only one potential failure mode in a process, for sure that the potential failure mode has failure mode ratio is equal to 1, because that process is ascertained will only do one potential failure mode. For example, pressing process has only one potential failure mode, which pressing force is not strong to release CNO and oil cake. This potential failure mode is assigned with value 1 for its failure mode ratio. Exactly same as on storing process that has only one potential failure mode, which is bottles place carelessly, is assigned with value 1 for its failure mode ratio.

Failure rate should be the most noticeable factor, because it is determined by how often a potential failure mode might be happened during the process occurs. Failure can be described as waste or defective product. For instance, potential failure mode knife is not sharp has failure rate equal to $5.4*10^{-3}$ failures per million hours. This number is obtained from within 8 hours observation, the knife can cut the whole copra 4000 kg, but in that whole quantity, there are 21.6 kg copra not be cut, so that quantity can be treated as failure rate. Within 8 hours observation, the company can produce 800 batches, which each batch consist of 5 liters. Among 800 batches, there are 24 bottles are found not in good quality, such as the taste is not like coconut oil as usual, but it leads to rust flavor or chemistry substance. Also, the color is not clear like coconut oil as usual, still contain brown color as rust or copra color and when oil in the bottle is tested, the shelf life time is not in appropriate time, which lead to deteriorate faster than expected time. By calculation, the failure rate is $3*10^{-2}$ failures per million hours. That kind of failure rate is belonged to some potential failure modes: knife and chopper is rusty, and chemistry substance is not in appropriate composition. Potential failure mode chopper is not sharp has failure rate equal to $1*10^{-3}$ failures per million hours. This number is obtained from within 8 hours observation, the chopper can grate the copra flesh 4000 kg, but in that whole quantity, there are 4 kg copra flesh not be completely grated. On pressing process, the input used for 8 hours processing time can produce 2000 liters coconut oil theoretically. But actually only 1760 liters can be produced, so the failure rate is $1.2*10^{-1}$ failures per million hours. For potential failure mode mesh is already full of residue, it occurs very rarely with failure rate only $6.25*10^{-4}$ failures per million hours. Among 800 batches that company produces within 8 hours observation, the result is only decreased by half batch. Deodorized material is not in appropriate composition has failure rate $2*10^{-2}$ failures per million hours. This number come from 16 batches are not qualified within 800 batches that are produced in 8 hours. On storing process, its potential failure mode is bottles place carelessly has failure rate $1.25*10^{-3}$ failures per million hours. This number is obtained from within 8 hours observation, there are 800 bottles produced. Among those 800 bottles, there is one unqualified bottle, so that quantity can be treated as failure rate.

The last factor that determines the final failure mode is operating time, which represents the time taken for doing observation to get number of failure rate. In this case study, total observation time taken is 8 hours. In usual way, this factor is shown in "seconds" time scale, so convert it become 28800 seconds. After gathering failure effect probability, failure mode ratio, failure rate, and operating time, then multiply that four factors become a new value called final failure mode. As example, for potential failure mode knife is not sharp with failure effect probability equal to 1, failure mode ratio equal to 0.48, failure rate equal to $5.4*10^{-3}$ failures per million hours, and operating time equal to 28800 seconds, then multiply it become final failure mode equal to $7.46496*10^{-5}$. In calculating the final failure mode, for failure effect probability which divide into two effects, it will be added up to 1, after that multiply with the other factors, so only has one value for its potential failure mode. For example, potential failure mode chopper is rusty with first effect is deterioration of oil has failure effect probability 0.009 and second effect is affect to the copra flesh's color has failure effect probability 0.991, add up together become 1, then multiply with failure mode ratio equal to 0.02, failure rate equal to $3*10^{-2}$ failure per million hours, and operating time equal to 28800 seconds, it become final failure mode equal to $1.728*10^{-5}$. Detail for failure effect probability, failure mode ratio, failure rate, operating time, and final failure mode of each potential failure mode on coconut oil and palm oil case study are described respectively on Table 12 and Table 13.

In qualitative approach, only two factors that are assigned on each potential failure mode, they are severity and occurrence. Those two factors are indicated as Criticality Priority Number (CPN). Severity description is related with potential effect of failure as a result from potential failure mode that might be happened on every process. While, occurrence description is related with failure rate, that represents number of expected failures happened during the process occur. Assigning severity and occurrence category is based on Tables 6 and 7, which had already adjusted with the case study at XYZ oil company. After assigning the severity and occurrence category on every potential failure mode, then convert it in terms of number to get CPN. Conversion for severity and occurrence category is based on Tables 8 and 9. For instance, for potential failure mode knife is not sharp with severity category III, means potential effect of failure not all copra can be completely cut into two portions is a kind of marginal failure, that is a failure which may cause minor inefficiency and/or ineffectiveness in the reconstruction of product, may takes time to reprocess it. On the same potential failure mode knife is not sharp with occurrence category B, is a kind of reasonably common failure, means a moderate probability of occurrence with failure rate more than 0.005, but less than 0.03 per million hours. Then, severity category III convert become CPN of 2, while occurrence category B convert become CPN of 4, and take average on both of them, become CPN of 3. Other potential failure mode that could be solved by reprocessing, such as chopper is not sharp enough, pressing force is not strong, and mesh is already full of residue are assigned with severity category III, and convert become CPN of 2. While the other potential failure mode that affects to change the taste or decrease shelf life time, such as knife and chopper is rusty, chemistry substance and deodorized material are not in appropriate composition, and bottles place carelessly are assigned with severity category II, and convert become CPN of 3. Regarding to occurrence category, some potential failure modes, like knife and chopper is rusty, pressing force is not strong, and chemistry substance is not in appropriate composition are assigned with category A, and convert become CPN of 5, because of its failure rate is equal or greater than 0.03 failures per million hours.

Table 12. Calculation of final failure mode of each potential failure mode on coconut oil case study

Failure ID	Potential effect(s) of failure	Failure effect probability	Failure mode ratio	Failure rate	Operating time	Failure mode
1.10	Not all copra can be completely cut into two portions	1	0.48	$5.4*10^{-9}$	28800	$7.46496*10^{-5}$
1.20	Deterioration of oil	1	0.02	$3*10^{-8}$	28800	$1.728*10^{-5}$
1.30	Not all copra flesh can be completely grated	1	0.48	$1*10^{-9}$	28800	$1.3824*10^{-5}$
1.40	Deterioration of oil	0.009	0.02	$3*10^{-8}$	28800	$1.728*10^{-5}$
	It affects to the copra flesh's color	0.991				
2.10	CNO yield is not maximum	1	1	$1.2*10^{-7}$	28800	$3.456*10^{-3}$
3.10	Too much: it affects to the oil taste	0.004	0.39	$3*10^{-8}$	28800	$3.3696*10^{-4}$
	Too less: the oil color is still in brown as copra color	0.996				
3.20	Much oils are stopped on the mesh	1	0.22	$6.25*10^{-10}$	28800	$3.96*10^{-6}$
3.30	Too less: deterioration of oil	0.571	0.39	$2*10^{-8}$	28800	$2.2464*10^{-4}$
	Too much: the deodorized material will be tasted	0.429				
4.10	Bottles place carelessly	1	1	$1.25*10^{-9}$	28800	$3.6*10^{-5}$

Table 13. Calculation of final failure mode of each potential failure mode on palm oil case study

Failure ID	Potential effect(s) of failure	Failure effect probability	Failure mode ratio	Failure rate	Operating time	Failure mode
1.10	Too much: it affects to the oil taste	0.004	0.39	$3*10^{-8}$	28800	$3.3696*10^{-4}$
	Too less: the oil color is still in red-orange as crude palm oil color	0.996				
1.20	Much oils are stopped on the mesh	1	0.22	$6.25*10^{-10}$	28800	$3.96*10^{-6}$
1.30	Too less: deterioration of oil	0.571	0.39	$2*10^{-8}$	28800	$2.2464*10^{-4}$
	Too much: the deodorized material will be tasted	0.429				
2.10	Bottles place carelessly	1	1	$1.25*10^{-9}$	28800	$3.6*10^{-5}$

Beside potential failure mode knife is not sharp with occurrence category B, deodorized material is not in appropriate composition also assigned with category B, because of its failure rate more than 0.005, but less than 0.03 per million hours. Rest of potential failure modes are assigned with category C, such as chopper is not sharp enough to grate the copra flesh, mesh is already full of residue, and bottles place carelessly, because its failure rate is more than 0.0005, but less than 0.005 per million hours. Occurrence category C convert become CPN of 3. After getting all CPN for every potential failure mode, then rank it from smallest to largest number to determine which potential failure mode should be prioritized to take actions on it. CPN with smallest number means the potential failure mode has least importance rate to be noticed, while largest number means the potential failure mode has most importance rate to be noticed. The following Table 14 and Table 15 show priority of each potential failure mode from the most important to the least one on coconut oil and palm oil case study, respectively.

Table 14. Priority of each potential failure mode on coconut oil case study

Failure ID	**Severity**	**Occurrence**	**CPN**	**Rank**
3.10	II	A	4	1
1.40	II	A	4	2
1.20	II	A	4	3
2.10	III	A	3.5	4
3.30	II	B	3.5	5
1.10	III	B	3	6
4.10	II	C	3	7
1.30	III	C	2.5	8
3.20	III	C	2.5	9

Table 15. Priority of each potential failure mode on palm oil case study

Failure ID	Severity	Occurrence	CPN	Rank
1.10	II	A	4	1
1.30	II	B	3.5	2
2.10	II	C	3	3
1.20	III	C	2.5	4

Table 14 and Table 15 give information that which potential failure mode should be prioritized to take actions on it, start from the most important to be noticed is chemistry substance is not in appropriate composition until the least one is mesh is already full of residue. On the Section 4.4 will discuss about some recommended actions to solve the problem in purpose of minimizing potential failure mode occur. Then, all of the recommended actions will also be evaluated on criticality analysis as well as on this section has already discussed about.

4.4 Recommended actions and criticality analysis

This section will discuss about some recommended actions that propose to reduce the probability of making the same failure mode as already described on Section 4.2. Recommended actions are proposed and discussed together with the process engineer of XYZ company, because that actions should be applicable on the production process of making coconut oil. As example, for potential failure mode knife is not sharp enough to cut the whole copra and knife is rusty might be anticipated by scheduling the appropriate time to sharpen and replace the knife. Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR) are one helpful time calculation as the input to find the appropriate time to sharpen and replace the knife. In coconut oil case study, MTBF can be calculated as the average time between failures (knife is not sharp and rusty) of a system, while MTTR represents the average time required to repair a failed component or device, that is to sharpen and replace the knife, done by technician. For potential failure mode chopper is not sharp enough to grate the copra flesh and chopper is rusty might be anticipated using the same idea as well as potential failure mode for knife on cleaving process. On pressing process, the potential failure mode pressing force is not strong might be anticipated by scheduling the appropriate time to do resetting the pressing machine, adopt MTBF and MTTR time calculation. MTBF is the average time between one time that the pressing machine can't be at maximum force and next time that the same failure occurs. MTTR is the average time required to do resetting the pressing machine. Potential failure mode chemistry substance and deodorized material are not in appropriate composition on bleaching and deodorizing process, respectively, might be prevented by finding the appropriate composition of chemistry substance and deodorized material. Design of Experiment (DOE) is the most used and useful design of any information-gathering exercises where variation is present, particularly the effect of adding or reducing chemistry substance and deodorized material to coconut oil product. By doing DOE, experimenter can do trial and error by setting some compositions of chemistry substance and deodorized material and analyze the effect to coconut oil, and make a final conclusion the appropriate composition of them. While on filtrating process, its potential failure mode mesh is already full of residue might be anticipated by scheduling the appropriate time to replace the mesh. Appropriate time could be gotten by calculating MTBF and MTTR, which MTBF is the average time between failures (mesh is already full of residue) and MTTR is the average time required to replace mesh with the new one. Besides that, to minimize the yield loss, it can be improved by adding a process after filtrating, such as pressing the mesh. For potential failure mode bottles place carelessly might be prevented by providing the suitable place near the worker who take in charge on it to arrange properly. Besides that, increase operator's awareness by organizing a training and exercise also important thing to prevent the placing on the inappropriate space.

Recommended actions will be done based on the prioritization that already made, since CPN with largest number means the potential failure mode has most importance rate to be noticed and anticipated as soon as possible to prevent become more severe and frequent. Recommended actions that already proposed will also be evaluated by assigning CPN of its potential failure mode. CPN is based on severity and occurrence factors as well as discussion on Section 4.3, which assigning severity and occurrence category are based on Tables 6 and 7, and its conversion become CPN is based on Tables 8 and 9. There are some reasons on assigning severity and occurrence category in its recommended actions. For instance, potential failure mode pressing force is not strong might be anticipated by scheduling the appropriate time to do resetting the pressing machine, is assigned on severity category III and occurrence category C, because if only do resetting, the setting might be changed automatically again, because of the life age of pressing machine itself. The following Table 16 and Table 17 show potential failure mode in failure ID term and its recommended action, followed by severity and occurrence category, also the CPN assigned on them. Table 16 is the application on coconut oil case study, while Table 17 is for palm oil case study.

Table 16. Potential failure mode, recommended action, and its CPN on coconut oil case study

Failure ID	Recommended actions	Severity	Occurrence	CPN
3.10	Finding the appropriate composition of chemistry substance	III	D	2
1.40	Scheduling the appropriate time to sharpen and replace the chopper	IV	E	1
1.20	Scheduling the appropriate time to sharpen and replace the knife	IV	E	1
2.10	Scheduling the appropriate time to do resetting the pressing machine	III	C	2.5
3.30	Finding the appropriate composition of deodorized material	III	D	2
1.10	Scheduling the appropriate time to sharpen and replace the knife	IV	D	1.5
4.10	Provide the suitable place and increase operator's awareness	III	D	2
1.30	Scheduling the appropriate time to sharpen and replace the chopper	IV	D	1.5
3.20	Scheduling the appropriate time to replace the mesh and add process	IV	C	2

Table 17. Potential failure mode, recommended action, and its CPN on palm oil case study

Failure ID	Recommended actions	Severity	Occurrence	CPN
1.10	Finding the appropriate composition of chemistry substance	III	C	2.5
1.30	Finding the appropriate composition of deodorized material	III	D	2
2.10	Provide the suitable place and increase operator's awareness	III	D	2
1.20	Scheduling the appropriate time to replace the mesh and add pressing process	IV	D	1.5

4.5 Comparison between before and after improvement

4.5.1 Coconut oil

After gathering CPN before and after improvement for coconut oil case study that already discussed on Section 4.3 and 4.4, respectively, the next step is making comparison between that two conditions, in purpose to know whether there is a change condition before and after improvement. Table 18 and Figure 5 show the CPN before and after improvement on coconut oil case study.

Table 18. CPN before and after improvement on coconut oil case study

Failure ID	CPN before improvement	CPN after improvement
3.10	4	2
1.40	4	1
1.20	4	1
2.10	3.5	2.5
3.30	3.5	2
1.10	3	1.5
4.10	3	2
1.30	2.5	1.5
3.20	2.5	2
Average	**3.333**	**1.722**

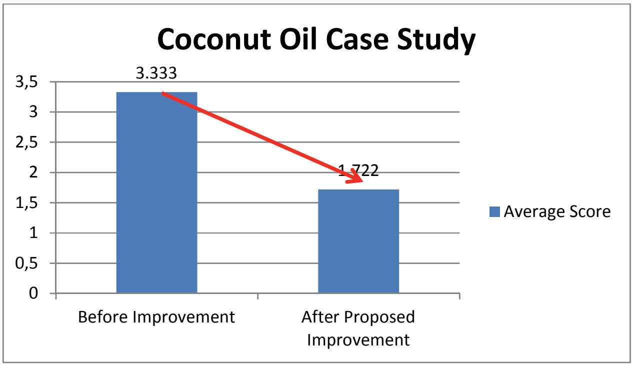

Figure 5. CPN before and after improvement on coconut oil case study

Using statistical test called two sample t-test to check whether after improvement is better significantly (use α-risk is 5%) compare with before improvement. Some assumptions must be checked and fulfilled before conducting two sample t-test. The first one is normality assumption.

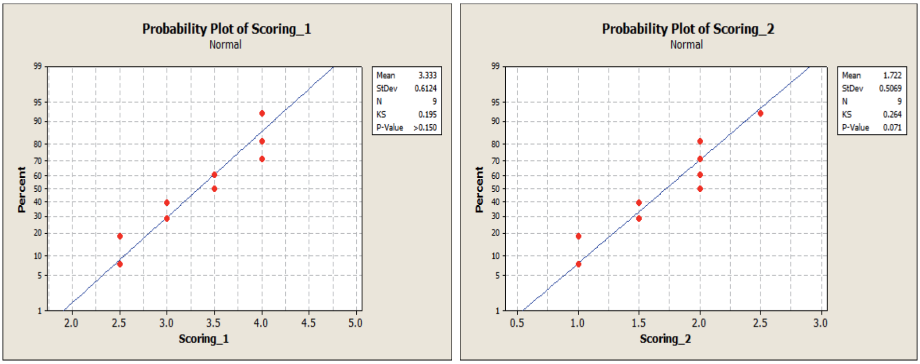

Figure 6. Normal probability plot CPN before and after improvement on coconut oil case study

Figure 6 depicts the result of normal probability test by plotting each data. The data refers to failure ID that already determined on Table 10. Probability plot of scoring_1 refers to CPN before improvement, while probability plot of scoring_2 refers to CPN after improvement. Probability plot of scoring_1 has P-value greater than 0.15, means CPN before improvement follows normal distribution, since its P-value is greater than α-risk (0.05). Probability plot of scoring_2 has P-value is equal to 0.071, also means CPN after improvement follows normal distribution. Second assumption is about the equality variance.

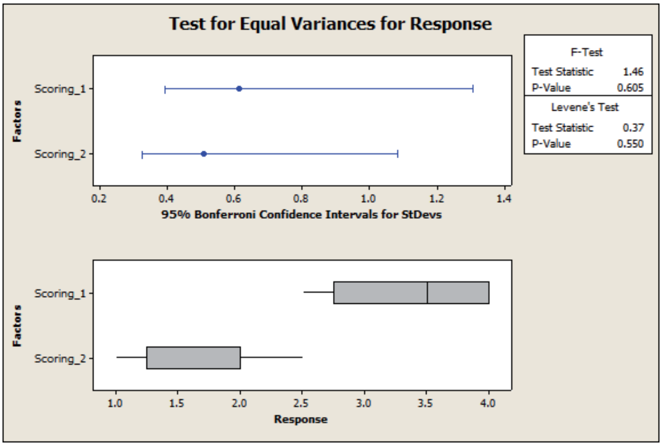

Figure 7. Test for equal variances for response on coconut oil case study

Figure 7 depicts the result of equality variances test by plotting factor scoring_1 and scoring_2 to CPN as the response. Since from the previous Figure 6 concludes that both scoring_1 and scoring_2 follow normal distribution, then in analyzing the equality variances use F-test, instead of Levene's test. P-value for F-test is equal to 0.605, which greater than 0.05 as α-risk, means variance of CPN before improvement is equal with variance of CPN after improvement.

Since the result of checking normality and equality variances are fulfilled, then continue to two sample t-test, which to test whether CPN of before improvement is significantly differ (greater than) with CPN of after improvement. Note that higher CPN means bad result, since on Tables 8 and 9 show that larger CPN indicates greater severity and probability of occurrence. The following is hypothesis for two sample t-test.

H_0: mean of CPN before improvement is equal with mean of CPN after improvement

H_1: mean of CPN before improvement is greater than mean of CPN after improvement

Result of two sample t-test is rejecting null hypothesis (H_0) with P-value is < 0.001, less than α-risk (0.05). It concludes that mean of CPN before improvement is significantly greater than mean of CPN after improvement, or in the other words say that recommended actions as proposed improvement gives less CPN significantly compare with condition before improvement. The result shows 48.33% lesser severity category and probability of making the same failure mode, from average CPN 3.333 to 1.722.

4.5.2 Palm oil

Similar with coconut oil case study, after gathering CPN before and after improvement for palm oil case study that already discussed on Section 4.3 and 4.4, respectively, the next step is making comparison between that two conditions. Table 19 and Figure 8 show the CPN before and after improvement on palm oil case study.

Table 19. CPN before and after improvement on palm oil case study

Failure ID	CPN before improvement	CPN after improvement
1.10	4	2.5
1.30	3.5	2
2.10	3	2
1.20	2.5	1.5
Average	**3.25**	**2**

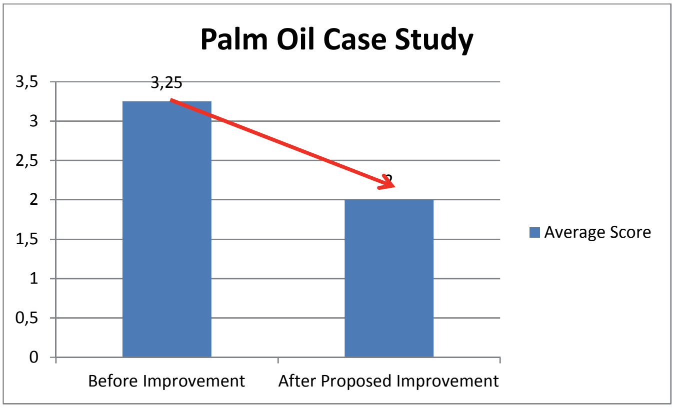

Figure 8. CPN before and after improvement on palm oil case study

The first assumption before conducting two sample t-test is normality assumption.

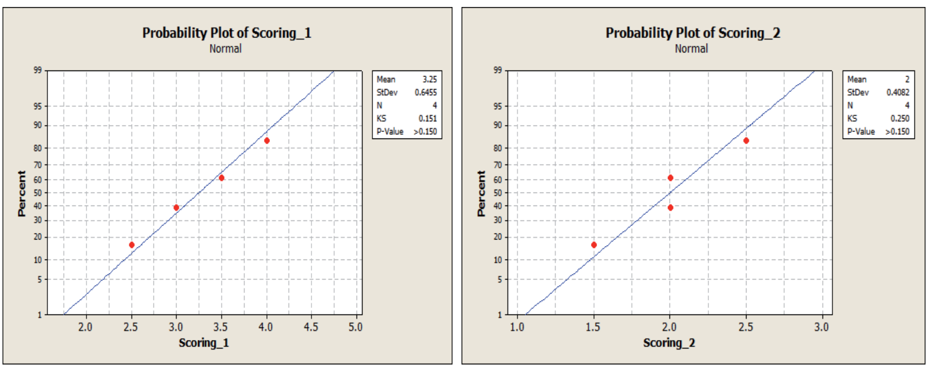

Figure 9. Normal probability plot CPN before and after improvement on palm oil case study

Figure 9 depicts the result of normal probability test by plotting each data. The data refers to failure ID that already determined on Table 11. Probability plot of scoring_1 has P-value greater than 0.15, means CPN before improvement follows normal distribution, since its P-value is greater than α-risk (0.05). Probability plot of scoring_2 also has P-value greater than 0.15, means CPN after improvement follows normal distribution. Second assumption is about the equality variance.

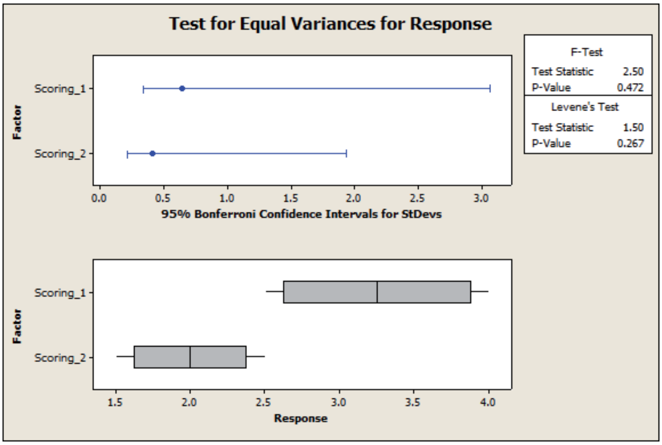

Figure 10. Test for equal variances for response on palm oil case study

Figure 10 depicts the result of equality variances test by plotting factor scoring_1 and scoring_2 to CPN as the response. Since from the previous Figure 9 concludes that both scoring_1 and scoring_2 follow normal distribution, then in analyzing the equality variances use F-test, instead of Levene's test. P-value for F-test is equal to 0.472, which greater than 0.05 as α-risk, means variance of CPN before improvement is equal with variance of CPN after improvement.

Since the result of checking normality and equality variances are fulfilled, then continue to two sample t-test. Result of two sample t-test is rejecting null hypothesis (H_0) with P-value is 0.008, less than α-risk (0.05). It concludes that mean of CPN before improvement is significantly greater than mean of CPN after improvement, or in the other words say that recommended actions as proposed improvement gives less CPN significantly compare with condition before improvement. The result shows 38.46%

lesser severity category and probability of making the same failure mode, from average CPN 3.25 to 2.

4.6 Failure mode effects and criticality analysis

This section will summarize all of the information regarding to coconut oil and palm oil case study that already gathered and discussed from Section 4.1 about production process of coconut and palm oil, Section 4.2 and 4.3 about critical process and its criticality analysis, and Section 4.4 about recommended actions and its criticality analysis. The output of Section 4.1 is process, sub process, and description or function of its process or sub process. The output of Section 4.2 is potential failure mode, potential effect of failure, and failure ID. The output of Section 4.3 is criticality analysis (both in quantitative and qualitative approach), CPN, and its rank. The output of Section 4.4 is recommended actions, criticality analysis in qualitative approach, and its CPN. Those four outputs are used as the input to build Failure Mode Effects and Criticality Analysis (FMECA). The following Table 20 is FMECA on coconut oil case study, while Table 21 is FMECA on palm oil case study.

Table 20. FMECA on coconut oil case study

Failure ID	Process	Sub Process	Description/Function	Potential Failure Mode	Potential Effect(s) of Failure
1.10	Cutting	Cleaving	Cutting whole copra into two portions	Knife is not sharp enough to cut the whole copra	Not all copra can be completely cut into two portions
1.20				Knife is rusty	Deterioration of oil
1.30		Chopping	Grating copra flesh into small parts	Chopper is not sharp enough to grate the copra flesh	Not all copra flesh can be completely grated
1.40				Chopper is rusty	Deterioration of oil It affects to the copra flesh's color, which has brown color as rust
2.10	Pressing		Pressing copra flesh to release Crude Nut Oil (CNO) and oil cake	Pressing force is not strong	CNO yield is not maximum
3.10	Refinery	Bleaching	Purifying the oil color (from brown as copra color into clear)	Chemistry substance is not in appropriate composition	Too much: it affects to the oil taste Too less: the oil color is still in brown as copra color
3.20		Filtrating	Filtrating the residue from bleaching process	Mesh is already full of residue	Much oils are stopped on the mesh
3.30		Deodorizing	Relieving the oil odor and moisture levels	Deodorized material is not in appropriate composition	Too less: deterioration of oil Too much: the deodorized material will be tasted
4.10	Storing		Fill oil into the bottle, store and keep away from the light and airflow	Bottles place carelessly	Early oxidation can be occurred

Table 20. FMECA on coconut oil case study (cont'd)

Failure ID	FEP (β)	FMR (α)	FR (λ_p)	OT (t)	FM (C_m)	SB	OB	CB	Rank	Recommended actions	SA	OA	CA
1.10	1	0.48	5.40E-09	28800	7.46496E-05	III	B	3	6	Scheduling the appropriate time to sharpen and replace the knife (adopt MTBF and MTTR)	IV	D	1.5
1.20	1	0.02	3.00E-08	28800	0.00001728	II	A	4	3		IV	E	1
1.30	1	0.48	1.00E-09	28800	1.3824E-05	III	C	2.5	8		IV	D	1.5
1.40	0.009 0.991	0.02	3.00E-08	28800	0.00001728	II	A	4	2	Scheduling the appropriate time to sharpen and replace the chopper (adopt MTBF and MTTR)	IV	E	1
2.10	1	1	1.20E-07	28800	0.003456	III	A	3.5	4	Scheduling the appropriate time to do resetting the pressing machine (adopt MTBF and MTTR)	III	C	2.5
3.10	0.004 0.996	0.39	3.00E-08	28800	0.00033696	II	A	4	1	Finding the appropriate composition of chemistry substance by doing Design of Experiment (DOE)	III	D	2
3.20	1	0.22	6.25E-10	28800	0.00000396	III	C	2.5	9	Scheduling the appropriate time to replace the mesh (adopt MTBF and MTTR) and add process	IV	C	2
3.30	0.571 0.429	0.39	2.00E-08	28800	0.0002246	II	B	3.5	5	Finding the appropriate composition of deodorized material by doing Design of Experiment (DOE)	III	D	2
4.10	1	1	1.25E-09	28800	0.000036	II	C	3	7	Provide the suitable place and increase operator's awareness	III	D	2

Table 21. FMECA on palm oil case study

FMEA Analysis					
Failure ID	**Process**	**Sub Process**	**Description/Function**	**Potential Failure Mode**	**Potential Effect(s) of Failure**
1.10		Bleaching	Purifying the oil color (from red-orange color into clear)	Chemistry substance is not in appropriate composition	Too much: it affects to the oil taste Too less: the oil color is still in red-orange as crude palm oil color
1.20	Refinery	Filtrating	Filtrating the residue from bleaching process	Mesh is already full of residue	Much oils are stopped on the mesh
1.30		Deodorizing	Relieving the oil odor and moisture levels	Deodorized material is not in appropriate composition	Too less: deterioration of oil Too much: the deodorized material will be tasted
2.10	Storing		Store oil into the bottle, keep away from the light and the airflow	Bottles place carelessly	Early oxidation can be occurred

Table 21. FMECA on palm oil case study (cont'd)

CA Analysis													
Failure ID	**FEP (β)**	**FMR (α)**	**FR (λ_p)**	**OT (t)**	**FM (C_m)**	**SB**	**OB**	**CB**	**Rank**	**Recommended actions**	**SA**	**OA**	**CA**
1.10	0.004 0.996	0.39	3.00E-08	28800	0.000337	II	A	4	1	Finding the appropriate composition of chemistry substance by doing Design of Experiment (DOE)	III	C	2.5
1.20	1	0.22	6.25E-10	28800	3.96E-06	III	C	2.5	4	Scheduling the appropriate time to replace the mesh (adopt MTBF and MTTR) and add pressing process	IV	D	1.5
1.30	0.571 0.429	0.39	2.00E-08	28800	0.000225	II	B	3.5	2	Finding the appropriate composition of deodorized material composition by doing Design of Experiment (DOE)	III	D	2
2.10	1	1	1.25E-09	28800	0.000036	II	C	3	3	Provide the suitable place and increase operator's awareness	III	D	2

Legend of Table:

FEP: Failure Effect Probability

FMR: Failure Mode Ratio

FR: Failure Rate

OT: Operating Time

FM: Failure Mode

SB: Severity Before improvement

OB: Occurrence Before improvement

CB: Criticality priority number Before improvement

SA: Severity After improvement

OA: Occurrence After improvement

CA: Criticality priority number After improvement

4.7 Criticality matrix

After FMECA is built, next step is building criticality matrix. In this matrix, it uses criticality analysis with qualitative approach as the input, which is severity and occurrence category. On x-axis depicts severity classification with four categories (I to IV), while on y-axis depicts occurrence classification with five categories (A to E). Criticality matrix includes failure ID both on condition before improvement (marked by red color) and after improvement (green color), so it can show the change between that two conditions. Each failure ID, which represents potential failure mode, will be depicted based on its severity and occurrence category that already determined on Table 14 and Table 16 for coconut oil case study, while Table 15 and Table 17 for palm oil case study. Criticality matrix on coconut oil and palm oil case study is depicted on Figure 11 and Figure 12, respectively.

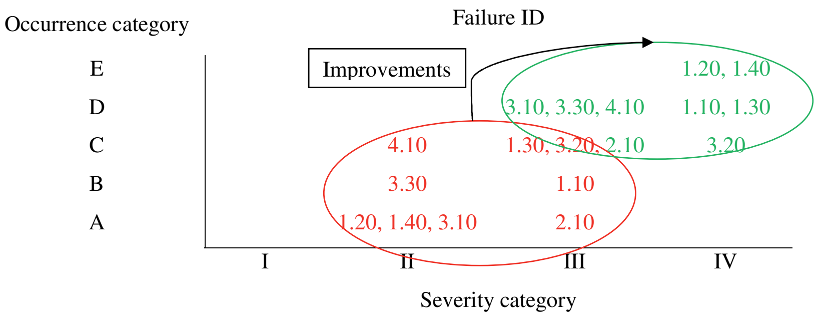

Figure 11. Criticality matrix on coconut oil case study

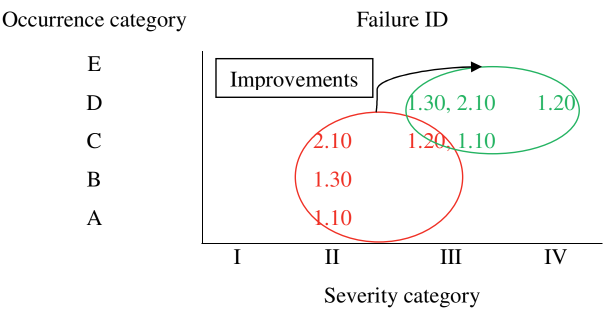

Figure 12. Criticality matrix on palm oil case study

Chapter 5
Conclusions and Future Research

5.1 Conclusions

This study has utilized Failure Mode Effects and Criticality Analysis (FMECA) approach in the Indonesian oil company. This approach begins with direct observation about the production process to make coconut and palm oil, then map its flow process. Next is going into FMECA analysis, that describes the detail about critical process and perform criticality analysis for each of it. Recommended actions are proposed to have improvement on reducing the criticality risk. Evaluate recommended actions by performing criticality analysis as well as on the initialization step and compare its changes. The conclusions can be summarized as follows.

(1) On coconut oil case study, there are four processes that had been found and detected as critical process. They are cutting process with cleaving and chopping as its sub process, pressing process, refinery process with bleaching, filtrating, and deodorizing sub process, and storing process. Cleaving sub process has two potential failure modes, which are knife is not sharp enough and rusty. Chopping sub process also has two potential failure modes, which are chopper is not sharp enough and rusty. Pressing process only has one potential failure mode, pressing force is not strong. Potential failure mode of bleaching sub process is chemistry substance is not in appropriate composition. Filtrating sub process has one potential failure mode, mesh is full of residue. Potential failure mode of deodorizing sub process is deodorized material is not in appropriate composition. Storing process also has one potential failure mode, bottles place carelessly.

(2) The result of assessment each potential failure mode on initial condition of coconut oil case study in a form of ranking list. The first potential failure mode that must be prioritized to take actions is chemistry substance is not in appropriate composition. Next one chopper is rusty, followed by knife is rusty, then continue with pressing

force is not strong. Deodorized material is not in appropriate composition places fifth rank, followed by knife is not sharp enough, then bottles place carelessly. The last two potential failure modes, chopper is not sharp enough and mesh is already full of residue.

(3) On palm oil case study, there are two processes that had been found and detected as critical process. They are refinery process with bleaching, filtrating, and deodorizing as its sub process, and storing process. Bleaching sub process only has one potential failure mode, chemistry substance is not in appropriate composition. Filtrating sub process also has one potential failure mode, mesh is full of residue. Potential failure mode of deodorizing sub process is deodorized material is not in appropriate composition. Storing process also has one potential failure mode, bottles place carelessly.

(4) Similar with coconut oil, the result of assessment each potential failure mode on initial condition of palm oil case study in a form of ranking list. The first potential failure mode that must be prioritized to take actions is chemistry substance is not in appropriate composition. Next one deodorized material is not in appropriate composition, followed by bottles place carelessly. The last rank, mesh is already full of residue.

(5) Recommended actions give better result significantly compare with before improvement. The result is related with safety improvement, which refers to lesser severity category and probability of making the same failure mode. Criticality priority number might be improved by 48.33% on coconut oil case study and 38.46% on palm oil case study.

5.2 Future research

As mentioned before that this study shows the application of FMECA to an oil company case study. However, FMECA is not a tool that can only be applied in an oil company, but it's also feasible to apply in another field, such as use before design commences in order to influence the design and uncover design risk. FMECA can be applied in electricity component design, food industry, automotive industry, and even for daily needs industry related with customer satisfaction. Basically, the content of FMECA is all the same even it applies on different field, because it has a standard form as problem solving tool to study problems that might arise from malfunctions of systems. The difference is only the basic principle of severity and occurrence classification. Even though those two classifications are adopted from a standard called US MIL-STD-1629A (Alion System Reliability Center, 1983), but the definition of each category might be different. It should be depends on the case type that is going to be analyzed on it.

Besides that, in analyzing the flow production process to produce something, it also need consider from other point of view, for example from customer, whether a process truly gives valuable effect to them or only favorable for producer. Checking the external supplier as third party to supply input or additional material is also important, because even the production process has been already ensured for safety importance, but the external factor has ruined at all, the safety itself is meaningless. Ensuring the scrap as non-qualified output to be not contaminated with qualified one is very substantial factor to prevent unexpectedly matter.

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