Operational risk evaluation and mitigation for palm oil supply chain: a case study at x co.

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Abstract. Risk analysis in the palm oil supply chain is essential to achieve the optimum efficiency and effectiveness of the supply chain flow. One of the most common types of risk found in the palm oil supply chain is operational risk. The objectives of the research were to model palm oil supply chain risk identification and to model its risk mitigation. Measurement of operational risk required in an effort to improve the performance of the palm oil supply chain, the method used in the assessment of this type of risk is Failure Mode and Effect Analysis-House of Risk (FMEA-HOR) through two stages of modeling, the analysis and evaluation stages used to know the risk event and risk agent known as HOR 1. Meanwhile the stages of risk mitigation measures applied to handle the potential risk types known as HOR 2. Based on the results of operational risk identification in the palm oil supply chain, 31 types of risk events and 20 risk agents were obtained. Furthermore, risk mitigation measures were based on the potential risk agents generated, converged into 8 risk proactive actions that are prioritized based on costs and resources effectiveness. The results of priorities proactive actions show that 1) maintenance’s labor training, 2) committing routine preventive and predictive maintenance, and 3) preparing alternate stand by equipment and machine units were necessary mitigation actions to be done.

Keywords: FMEA-HOR, palm oil supply chain, risk agent, risk event

1. Introduction

Indonesia dominancy in palm oil production respectively can be seen from plantation area growth and palm oil agroindustry itself, considered of high profit margins while the palm oil production are simple and low in costs. Furthermore, the significant increase of palm oil global demand made the business interesting and open up the opportunities for palm oil stakeholders due to the important roles of this sector in affecting national economy and improving community welfare [1], [2]. However, along with the increasing of palm oil supply chain, there are unavoidable impacts and pressures in Indonesia’s CPO exports which gave influences on the operational sustainability of palm oil agroindustry thats are directly related to the palm oil supply and demand stabilization [3], [4]. This things need to be considered due to its direct relation to the impacts that arise as potential risks to the palm oil supply chain because of economic and social changes from various palm oil supply chain stakeholders, also the black campaign or market sentiment towards palm oil [4]. As an example, in a palm oil agroindustry company, the impact can cause a loss or decrease in company profits and further lead to money loss and unemployment of employess as a social impact. Likewise for palm oil farmers, if there are incompatibility in the cultivation processing until harvesting, it will cause effects to the price and production continuity, therefore the palm oil farmers will receive lower incomes [5].
Hence, it is required to consider palm oil supply chain activities’ diverse risks due to the issue of risk and uncertainty in agriculture and the decisions relating to risks are needed [6] and also needed to optimize supply chain [7]. According to internal and external occurrence of risk in supply chain management factors [8], the frequently types of risks appear is the operational risk factor [9], [10]. These operational risk factors are namely faults planning, raw material shortages, capacity constraints, machine failure or down time, imperfect results, inefficiencies, process changes, property losses due to accidents/disasters, transportation risks (delays, damage during expedition), warehouse risks (imperfect costumer orders, insufficient inventory, and others), budget expenditures, technology disruptions’ emergence, terms of agreement (minimum and maximum costumer requests), and interruptions of communication or information system [11].

Considering to the direct impacts of operational risks on palm oil supply chain performance, a measurable and systematic investigation is needed to mitigate these type of risks. Through to the supply chain risks identification, it can be found the overall risks data and information that occur in supply chain that can be optimally utilized to obtain the mitigation actions from palm oil supply chain problems to improve the supply chain performance. This background makes the study of supply chain agricultural risks done a lot and some studies has already proposed several method such as sustainable palm oil supply chain risk judgment based on performance [9], risk balancing model of agro-supply chain [12], agent based modelling for palm oil supply chain operational risk [13], supply chain risk in organic rice product using Fuzzy-FMEA method [14], poultry feed production’s risk analysis using Fuzzy-FMEA [15], supply chain risk in rafinated sugar using HOR method [10], and fuzzy logic for risk dependency chain in dairy agroindustry [16]. Yet, the types of risks involved in palm oil supply chain are different and to our knowledge, there is no research has been investigate this operational risk in the palm oil supply chain. Thus, this paper will investigate palm oil supply chain operational risk and proposed risk mitigation actions.

Moreover, it is necessary to analyze the palm oil supply chain risk factors and its treatment that can be applied. The purposes of this research were to model supply chain risk identification, calculate and analyze the risk priority index value to the causes of risk in palm oil supply chain activities, and to conducts palm oil supply chain risk mitigation modelling based on potential risk index. In order to fulfill these objectives, this research uses House of Risk method to evaluate the types of potential risks and evaluate it, and mitigation model for potential risks obtained. House of Risk (HOR) modelling is a modification method to prioritize potential risk agent that are chosen to get effective actions in achieving objectives to reduce potential risks from risk event. From the statement above, it is known that HOR method is beneficial because its ability to integrate the risk identification till risk mitigation in one comprehension model, but the drawback of the method is time consuming and complexity data is needed to build the model.

2. Methodology

2.1. Research Framework

House of Risk (HOR) is a modification method of FMEA (Failure Mode and Effect Analysis) and House of Quality (HOQ) models to select and prioritize risk agent that will be given the action in purpose to decrease the risk agents’ potencies [10]. Risk assessment using FMEA is well-known done through quantitative score to the risk priority number (RPN) as a mathematical model of the risks to identify the most critical failure mode, leading to corrective actions [15], [17]. Different from the FMEA model, where both the severity and occurrence are correlated with the risk events, in FMEA-HOR the occurrence is assigned to the risk agents and the severity is assigned to the risk events and measure the Aggregate Risk Potential (ARP) of a risk agent. The HOQ model is adapted to conclude which risk agents should prioritize for preventive actions due to each risk agent’s rank [18].

The HOR model is depend on the nation that a preventive supply chain risk management should attempt to concern on proactive actions [18] that would prevent the risk events to appear. In determining HOR’s risk analysis, it is based on the SCOR (Supply Chain Operations Reference) business process parameters model to represent, analyze, and configure the supply chains based on its basic pillars: plan,
source, make, deliver, and return [8], [19] in order to describe business process along palm oil supply chain that centralize the risk event, risk agent, and preventive or mitigation actions of risk agents. From the supply chain, it will be carried out some problems mitigation that may arise out of the supply chains before the impacts realized spread [20].

House of Risk (HOR) method used in this paper divided to two deployments models, called HOR 1 and HOR 2. The HOR 1 is used to identify, analyze, and determine the risk agents and the risk events which are to be measured and prioritize the potential risk agents as the evaluate step. The HOR 2 is used to provide preventive actions considered effective but with acceptable costs and resources.

2.2. Data Collection Procedure

The data used in this research were obtained from primary dan secondary sources. The primary data used was resulted from field observation, questionnaires, interviews, and experts’ discussion. The field observation was conducted in X Co., Cigudeg, West Java, Indonesia about supply chain operational risks and experts assessment for each risks measurement and risks mitigation. The secondary data was used from scientific study, previous research, and other relevant data.

2.3. House of Risk 1 Data Analysis

2.3.1. Risk Identification. The risk identification begins with a supply chain structures preliminary study and supply chain members relationships. It is conducted as an evaluation and efficiency control of the business process [20] and extensively able to control each dimension of the supply chain and detected the whole business process activities. Data collection is done through literature study, field observation, filling out questionnaires, and in-depth interviews with industry practitioners (professionals) involved in the palm oil supply chain. The supply chain risks is assessed due to severity of risk events and occurrence of risk agents based on the FMEA approach and identified based on model and alternative adjustments according to company needs. Each of indicators determine directly using depth interview with the expert and interpreted in the HOR modelling and determined critical points of each activities.

2.3.2. Risk Analysis. The risk analysis is performed by determining risk events’ severity (Si), risk agents’ occurrence (Oj), and risk event and risk agent’s correlation (Rij). The severity value using 1-10 scale (no failure-must occurred failure), occurrence value using 1-10 scale (almost never happened-often), and correlation with Rij (0, 1, 3, 9); 0 is no correlation and 1, 3, 9 show low, moderate, and high correlation, correlation relationship is expressed as Rij ∈ {0, 1}, Rij=1, there is correlation between risk i with risk agent j and Rij=0, there isn’t correlation between risk i and the risk agent j. The weighting of risk components (as a modified aggregation method from the previous HOR researches) is carried to provide its value, through the use of formula for experts combination [21]:

\[
Si = \text{median} [S_{i1}, S_{i2}, \ldots, S_{ik}] \quad \forall i
\]

(1)

\[
Oj = \text{median} [O_{j1}, O_{j2}, \ldots, O_{jk}] \quad \forall j
\]

(2)

Si = Severity level of risk event  
Oj = Occurrence level of risk agent  
\( i, j = 1, 2, \ldots, n \)

The calculation of the risk aggregation value is obtained by calculating the ARPj value [18]:

\[
P_j = \sum_{i=1}^{m} \frac{R_{ij}}{S_i} \quad \forall j
\]

(3)

2.3.3. Risk Evaluation. The risk evaluation aims to determine ARPj ranking to risk priority, potential impacts of risk event, and correlation among risk agents of HOR 1’s roof. After the ARPj value (risk analysis’ result) obtained, the rank is made using the formula as follows [22]:

\[
P_j = \sum_{i=1}^{m} \frac{R_{ij}}{S_i} \quad \forall j
\]

(4)

Pj = Risk priority index  
Oj = Occurrence level of risk agent  
\( i, j = 1, 2, \ldots, m; R_{ij} \in \{0,1\} \)  
wij = The weighted correlation between risk event i with risk agent j
Furthermore, from ARP value rank, the risk mitigation is conducted using Pareto diagram (80:20 rule) which gives sequencing classification data description to find the most important risk agents to resolve and mitigate immediately [22]. In general, the HOR 1 stages are carried out as follows:

1. Identification of weaknesses and risk events in each business process is done as the result of supply chain business process mapping.
2. The risk events’ estimating impacts assess with the 1-10 scale value (shows the severity (Si)).
3. The determination of the potential caused/impact by each risk event, expressed as Ci, determined by experts who are experienced in their field.
4. The occurrence’s frequency of each risk agents determined with a set of 1-10 scale (Oj).
5. The matrices relationships development. Determine the relationship among risk agent and risk event, Rij (0, 1, 3, 9), 0 shows no correlation and 1, 3, 9 show low, medium, and high correlations.
6. The calculation of potential risk value (Aggregate Risk Potentials of risk agent j = ARPj) is determined as in the equation ARPj = Oj Σ Si Rij
7. The relationship among risk agents determine using Rajj notation (0, θ, *, •); 0 shows no correlation and θ, *, • respectively show weak, moderate, and strong correlation [22].
8. The ranking determination of risk agents based on the ARPj value.

2.4. House of Risk 2 Data Analysis
House of Risk 2 modeling is applied to decide the risk mitigation actions carried out by considering the resources and costs effectiveness in mitigate the risk agents so that it is not difficult to implement and effectively reduces the occurrence of risk agents. The steps taken for the risk mitigation process are, identify the risk mitigation, evaluate the risk mitigation, determine the correlation among mitigation actions, and select the mitigation actions priority. The steps of HOR 2 model are explained below:

1. Choose a number of risk agents with high priority rank based on ARPj’s Pareto analysis, placed as to be treated risk agent (Aj).
2. Identify the relevant preventive or proactive action which simultaneously can decrease the possibility of more than one risk agents’ occurrence, the action called preventive action (PAk).
3. The correlation value (Ejk) weighting of risk agent and its mitigation action, using Ejk scale (0, 1, 3, 9). Ejk can be considered as the actions’ effectiveness level in reducing the risk agents occurrence.
4. The calculation of each total effectiveness actions: TEk = ARPjEjk ∀kj
5. Estimated the preventive actions with actions difficulty degree. Dk (difficulty) using Likert scale (3, 4, 5) which reflects the costs and other resources needed to carry out these risk mitigation actions.
6. The calculation of total effectiveness with difficulty, ETdk = TEk/Dk. Determine each of actions’ priority level (Rk), the first level indicates the action with the highest ETdk.
7. The relationship among mitigation actions determine using Rajj notation (0, θ, *, •); 0 shows no correlation and θ, *, • respectively show weak, moderate, and strong correlation [22].

3. Results and Discussions
3.1. Palm Oil Supply Chain’s Operational Risk Analysis (House of Risk 1)
Palm oil supply chain performance which has not reached the maximum value as in [8] indicate the needs to evaluate and increase its performance level because it could be regarded as a loss caused by the supply chain problems that directly or indirectly disturb the palm oil supply chain, which is defined as a supply chain risk. Septiani [23] also mentions that the supply chain risks are interconnected and affect the supply chain performance. The risk identification is conducted on the palm oil business process, based on the SCOR dimension decomposed into each subprocess so that common or potential errors or risks occur throughout the supply chain can be known in detail [16]. Therefore, it is necessary to control the supply chain risk in order to avoid the ongoing and sustainable effects that occur at every point in supply chain network by carrying out the supply chain risk analysis [24]. Supply chain risk analysis from the operational side using HOR method is determine by doing risk event identification, risk agent identification, and its correlation.
3.1.1. **Risk event identification.** The risk event identification is carried out in plan, source, make, deliver, and return stages of the palm oil supply chain business process [8] which are break down into each sub-process, so the details of faults or risks that are common and potentially occur along the supply chain can be known [16]. The identification is based on the critical points of each sub-process activities related to the palm oil supply chain impacts. Based on the results of risk identification conducted, it determines 31 risk events as the critical point that linked to the impact of supply chain. The identification result of the risk events with the severity result depicted in appendix A.

3.1.2. **Potential impact identification.** Identification of risk event’s possibility effect (potential impact) is shown in appendix B, the potential impact declaring the disturbance that might arise if a risk event occurs [21]. The potential impact of 31 risk events is the result of the competent experts’ judgement.

3.1.3. **Risk agent identification.** The risk agent identification is based on the results of previous identified risk events. Each of identified risk agents may present one/more risk events and vice versa, one risk event may be caused by one/more risk agents causing the disruption [18], the identification result of palm oil supply chain risk agents and its occurrence is obtained as shown in table 1.

| Code | Risk Agent                                                                 | Oj |
|------|---------------------------------------------------------------------------|----|
| A1   | Production planning miscalculation                                        | 1  |
| A2   | Sudden/unexpected demand from consumers                                  | 1  |
| A3   | Insufficient of raw material to production capacity                       | 1  |
| A4   | Incompetent labors                                                       | 1.5|
| A5   | The wrong selection of raw material suppliers                            | 1  |
| A6   | The supplier does not fulfill contract                                    | 1  |
| A7   | Technical disturbance/production stagnation                               | 4.5|
| A8   | The production target is relatively high                                  | 3  |
| A9   | The defect to machine production                                          | 5  |
| A10  | The lack of production machines’ maintenance                              | 1.5|
| A11  | Negligence of labor                                                      | 2  |
| A12  | Overlong stacking of raw material/product                                 | 2.5|
| A13  | Raw materials defect during transportation                                | 2  |
| A14  | Process efficiency factor                                                 | 3  |
| A15  | Reliability factor of process machine and equipment                       | 3  |
| A16  | The decline of product quality during transportation                      | 2.5|
| A17  | The lack of coordination in the shipping process                          | 1.5|
| A18  | The distance and communication factors between producers and consumers    | 1  |
| A19  | Environmental conditions                                                 | 1  |
| A20  | Limited transportation facilities                                         | 2  |

3.1.4. **The correlation between risk event and risk agent.** The analysis between each risk event and risk agent correlation is shown in the 0, 1, 3 and 9 value scales based on each level of each other correlation. The correlation is defined if a risk agent occurs, due to the emergence of risk events with each level of correlation low, medium, and high based on expert judgment. For example, due to production planning miscalculation (A1), it results several risk events, such as incompatibility between capacity planning and processing realization (E1), the gap between planning and on-hand material (E2), supply chain incompatibility with cost budget (E3), production target is not achieved (E5), raw materials don’t meet the capacity planning (E7), the changes in the raw materials quality (E10), non-conformity of material sent by supplier (E12), the production process is inefficient (E15), production activities aren’t
done/stopped (E21), the demand can’t be fulfilled (E22), the lack of products in the distribution center (E25), and the stability of production is disrupted (E29) as shown in appendix C. It is known, that from one risk agent (A1) can results 12 risk events, so that if a risk agent can be handled or mitigated then the risk event can be reduced or even eliminated.

3.1.5. The correlation among risk agents. The correlation among risk agents in the House of Risk 1 is placed in the HOR’s roof component which states the risk agents’ correlation. The correlation consists of four categories, namely a strong correlation (•) if a risk agent will have a very significant influence with other risk agent, a moderate correlation (*) if a risk agent will provide enough influence with other risk agent, weak correlation (•) if a risk agent will provide a weak relationship with other risk agent, and there is no correlation (θ) between risk agents. From 20 risk agents identified, the relationship/correlation among risk agents as shown as the roof in appendix C.

3.1.6. Aggregate risk potentials analysis. Risk measurement preparation as a series of coherent, systemic, and explicit actions that accomodate the risk correlated to the supply chain activities [25]. The weight determination of each risks occured is based on the experienced experts assessment, resulting Aggregate Risk Potentials (ARP) value from the result of severity, occurence, and the correlation will be used to determine the risk priority to handle, shown in table 2.

Based on the results of ARP value priority’s calculation, it shows that the order for 20 identified risk agents, it is known that the highest value of ARP is the defect to machine production (A9) while the lowest value is the decline of product quality during transportation (A16). From the overall of ARP value results, then it is conducted the analysis using Pareto diagram to prioritize mitigations will be given. Depend on the classification, there are 8 risk agents selected prioritized to mitigate. Sequentially, the results of ARP value calculation then classified according to Pareto diagram to select the priority of risk agents from the overall risk to be handled as an effort to minimize the risk occurrences. The risk agents classification is based on the Pareto 80:20 diagram, then classified into 3 classifications; i.e. classification A (high-level risk agents, 50% of overall risk agents), classification B (medium-level risk agents, 30% of overall risk agents), and classification C (low risk agents, 20% of overall risk agents) [9]. The classification results indicate that 50% of the risk sources in classification A (emerging rate of 56.29%), 30% risk sources in classification B (26.37% incidence rate), and 20% in classification C (17.34% incidence rate) as displayed in Table 2. The overall HOR 1 model as depicted in appendix C.

3.2. Risk Mitigation Analysis (House of Risk 2)
Risk mitigation actions are proposed based on selected potential risks for corrective action, conducted in the form of risk reduction, risk-transfer, risk-aversion, and risk-taking [15]. The risk mitigation model refers to every effort to identify and manage/prevent risks from happens and make sure this situation handled [7]. Risk handling stages are conducted by giving effective mitigation action to decrease the risk agents possibility’s priority based on the House of Risk 2 model. Based on the risk agents ranking, the preventive measures identified are divided into 8, there are performing the preventive and predictive maintenance on a regular basis (PA1), preparation of stand by equipment and machine units as substitutes the engine failure (PA2), coordination management and related sections (PA3), improved production design based on the suitability of field conditions (PA4), improved cooperation and coordination with stakeholders related to raw materials (PA5), coordination with the transporter (PA6), optimization of production process in accordance with the provisions and work instructions (PA7), the labors’ training on maintenance (PA8). Completely, HOR 2 modelling as depicted in figure 1.
Table 2. The ARP value priority for risk agent.

| Rank | Code | Risk Agent                                                   | ARP Value | % Total | Cumulative ARP | ABC Class |
|------|------|--------------------------------------------------------------|-----------|---------|---------------|-----------|
| 1    | A9   | The defect to machine production                            | 1680      | 28.62   |               | A (high level risks) |
| 2    | A7   | Technical disturbance/production stagnation                 | 1224      | 49.48   |               |           |
| 3    | A12  | Overlong stacking of raw material/product                   | 400       | 56.29   |               | B (medium level risks) |
| 4    | A13  | Raw materials defect during transportation                   | 368       | 62.56   |               |           |
| 5    | A8   | The production target is relatively high                    | 360       | 68.69   |               |           |
| 6    | A10  | The lack of production machines’ maintenance                | 350       | 74.66   |               |           |
| 7    | A15  | Reliability factor of process machine and equipment          | 243       | 78.8    |               |           |
| 8    | A1   | Production planning miscalculation                          | 227       | 82.66   |               |           |
| 9    | A14  | Process efficiency factor                                   | 210       | 86.24   |               |           |
| 10   | A11  | Negligence of labor                                         | 156       | 88.9    |               |           |
| 11   | A3   | Insufficient of raw material to production capacity          | 150       | 91.46   |               |           |
| 12   | A4   | Incompetent labors                                          | 104       | 93.23   |               |           |
| 13   | A5   | The wrong selection of raw material suppliers               | 85        | 94.68   |               |           |
| 14   | A19  | Environmental conditions                                    | 67        | 95.82   |               |           |
| 15   | A20  | Limited transportation facilities                            | 54        | 96.74   |               |           |
| 16   | A2   | Sudden/unexpected demand from consumers                     | 48        | 97.56   |               |           |
| 17   | A18  | The distance and communication factors between producers and consumers | 44 | 98.3 | | |
| 18   | A6   | The supplier does not fulfill contract                      | 35        | 98.9    |               |           |
| 19   | A17  | The lack of coordination in the shipping process            | 34.5      | 99.49   |               |           |
| 20   | A16  | The decline of product quality during transportation         | 30        | 100     |               |           |

3.2.1. The correlation between risk agent and mitigation action. The analysis between each risk agent and mitigation action correlation that will be handled with the planned mitigation action is shown in the 0, 1, 3, and 9 scale value based on each other level of correlation. The correlation is defined as the effectiveness of a mitigation action in reducing the risk agent. Performing the preventive and predictive maintenance on a regular basis (PA1) mitigation action shows 9 value (high correlation) with the defect to machine production (A9), technical disturbance/production stagnation (A7), the lack of production machines’ maintenance (A10), and reliability factor of process machine and equipment (A15) risk agents. The other correlation between mitigation actions (PAk) and its risk agent as shown in figure 1.

3.2.2. The correlation among risk mitigation actions. The correlation among risk mitigation actions in the HOR 2 is place in the HOR’s roof component that states each of mitigation action correlation. The correlation consists of four categories, namely a strong correlation (●) if a mitigation action will have a very significant influence with other mitigation action, a moderate correlation (●) if a mitigation action will provide enough influence with other mitigation action, weak correlation (θ) if a mitigation action will provide a weak relationship with other mitigation action, and there is no correlation (0) between mitigation actions. From 8 mitigation actions identified, the relationship/correlation among mitigation actions as shown above in figure 1.
3.2.3. Risk mitigation action priority. Risk mitigation actions assessment is performed by considering the costs and resources effectiveness, each actions’ total effectiveness calculation, and difficulty level (Dk) of implementation; to conclude the effectiveness value to mitigation action as shown in table 3. The result of mitigation action as the solution or alternative for the risk agents, i.e. the PA8 action which has the highest rank will minimize the correlated risk agents and so on as described in 3.2.1 section.

Table 3. Mitigation actions’ rank.

| Rank | Code | Mitigation Action                                                                 | TEk  | Dk  | ETD  |
|------|------|----------------------------------------------------------------------------------|------|-----|------|
| 1    | PA8  | The labors’ training on maintenance                                             | 29529| 3.5 | 8436.86 |
| 2    | PA1  | Performing the preventive and predictive maintenance on a regular basis          | 31473| 4   | 7868.25 |
| 3    | PA2  | Preparation of stand by equipment and machine units as substitutes the engine failure | 28323| 4.5 | 6294  |
| 4    | PA3  | Coordination management and related sections                                    | 6721 | 3   | 2240.33 |
| 5    | PA7  | Optimization of production process in accordance with the provisions and work instructions | 5169 | 3   | 1723  |
| 6    | PA4  | Improved production design based on the suitability of field conditions         | 4907 | 3.5 | 1402  |
| 7    | PA6  | Coordination with the transporter                                               | 3968 | 3   | 1322.67 |
| 8    | PA5  | Improved cooperation and coordination with stakeholders related to raw materials | 1464 | 3   | 488   |

Based on the priority mitigation actions measures with consideration to the resources and costs effectiveness, the handling risk results are classified in the Pareto diagram to select the best and feasible action as shown in figure 2. The accumulated results of the effectiveness action level percentage indicate four priority actions which is included in 83.42% of the total value. The mitigations’ priority are the
labors’ training on maintenance (PA8=28.34%), performing the preventive and predictive maintenance on a regular basis (PA1=26.43%), preparation of stand by equipment and machine units as substitutes the engine failure (PA2=21.14%), and coordination management and related sections (PA3=7.52%).

Figure 2. Pareto diagram of mitigation actions’ ETD

4. Conclusions and Recommendations
The operational risk identification by using the House of Risk approach concluded 31 risk events and 20 risk agents that obtained in all palm oil supply chain business process phases. From the HOR 1 model, it was known that each of risk events had correlations to risk agents with various values and generates aggregate values of potential risk agents that form the framework for implementing mitigation actions. From the 20 risk agents identified, 8 risk agents were selected to get preventive action immediately in HOR 2. In the HOR 2 model, 8 mitigation actions were prioritized to be implemented based on resources and costs effectiveness. There were four priority mitigation actions, 1) the labors’ training on maintenance, 2) performing the preventive and predictive maintenance on a regular basis, 3) preparation of stand by equipment and machine units as substitutes the engine failure, and 4) coordination management and related sections.

For further research, it is necessary to conduct a broader analysis substance and detail identification to other types of potential risks through overall information and each palm oil supply chain actors especially related crucial actors such as smallholder farmers as the main suppliers of palm oil who do have uncertainty positions due to its situational conditions. In addition, to facilitate work in this digitalization era, an integrated information system related to the palm oil supply chain is needed.

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### Appendix A. The possibility of risk event based on business process.

| Sub Process                          | Risk Event                                                                 | Code | Si |
|--------------------------------------|-----------------------------------------------------------------------------|------|----|
| **Plan**                             |                                                                             |      |    |
| Production capacity design           | Incompatibility between capacity planning and processing realization         | E1   | 4  |
|                                      | The gap between planning and on-hand material                               | E2   | 4  |
| Raw materials control                | Supply chain incompatibility with cost budget                               | E3   | 4  |
| Adjustments of supply chain and cost |                                                                             |      |    |
| planning                             |                                                                             |      |    |
| Perfect condition                    |                                                                             |      |    |
| Source                               |                                                                             |      |    |
| Raw material delivery’s acceptance   |                                                                             |      |    |
|                                      | The resulting yield doesn’t meet the standard                               | E4   | 4  |
|                                      | Production target is not achieved                                          | E5   | 4  |
|                                      | The delay of raw materials from suppliers and plantations                   | E6   | 4  |
|                                      | Raw materials don’t meet the capacity planning                              | E7   | 4  |
|                                      | The low quality of raw material supply                                      | E8   | 4  |
|                                      | Raw materials that do not match/don’t pass sorting process                  | E9   | 4  |
| Supplier selection and evaluation    |                                                                             |      |    |
|                                      | The changes in the raw materials quality                                   | E10  | 4  |
|                                      | Not evaluating supplier performance                                        | E11  | 4  |
| Make                                 |                                                                             |      |    |
| Production control                   |                                                                             |      |    |
|                                      | Delays in the production implementation                                     | E14  | 7  |
|                                      | The production process is inefficient                                       | E15  | 5  |
|                                      | Engine failure (machine breakdown or lack of maintenance)                    | E16  | 8  |
|                                      | The output isn’t perfect                                                    | E17  | 4  |
|                                      | Inhibition of production due to mechanical damage                           | E18  | 6  |
| Product quality checks               |                                                                             |      |    |
|                                      | No quality checks are conducted during the process                          | E19  | 4  |
| Production activity                  |                                                                             |      |    |
|                                      | The defect in products yield                                                | E20  | 4  |
| Deliver                              |                                                                             |      |    |
| Delivery selection                   |                                                                             |      |    |
|                                      | The lack of product delivery capacity                                       | E24  | 4  |
|                                      | The lack of products in the distribution center                             | E25  | 3  |
|                                      | Delayed delivery of products to consumers                                  | E26  | 4  |
|                                      | Damage to the product during transportation                                 | E27  | 4  |
| Return                               |                                                                             |      |    |
| Raw material returns                 |                                                                             |      |    |
|                                      | The quantity of raw materials is not suitable                               | E28  | 4  |
|                                      | The stability of production is disrupted                                    | E29  | 5  |
|                                      | The cost of the products reprocessing                                       | E30  | 4  |
|                                      | Rescheduling delivery                                                       | E31  | 4  |
### Appendix B. Risk event’s potential impact.

| Code | Risk Event                                                                 | Potential Impact                                                      |
|------|---------------------------------------------------------------------------|----------------------------------------------------------------------|
| E1   | Incompatibility between capacity planning and processing realization      | Unachieved production target, production process is disrupted         |
| E2   | The gap between planning and on-hand material                             | Production stability is disrupted, unachieved production capacity     |
| E3   | Supply chain incompatibility with cost budget                             | Ineffecient system, increasing of the total costs                     |
| E4   | The resulting yield doesn’t meet the standard                             | Low selling price, company losses                                     |
| E5   | Production target is not achieved                                         | Unfulfilled orders, company losses                                    |
| E6   | The delay of raw materials from suppliers and plantations                 | Idle capacity                                                         |
| E7   | Raw materials don’t meet the capacity planning                            | Unmaximum holding capacities                                          |
| E8   | The low quality of raw material supply                                     | The yield doesn’t meet the standards/low quality                      |
| E9   | Raw materials that do not match/don’t pass sorting process                | The yield doesn’t meet the standards/low quality, CPO’s price is low  |
| E10  | The changes in the raw materials quality                                  | Products quality get drop and CPO’s price is low                      |
| E11  | Not evaluating supplier performance                                       | Raw materials quality is low                                           |
| E12  | Non-conformity of material sent by supplier                               | Products quality get drop and CPO’s price is low                      |
| E13  | The raw material is broken so it can’t be processed                       | Unachieved production target                                           |
| E14  | Delays in the production implementation                                   | Orders are not met, delivery schedules’ disruptions                   |
| E15  | The production process is inefficient                                     | Increased costs                                                       |
| E16  | Engine failure (machine breakdown or lack of maintenance)                  | Unachieved production target, maintenance additional costs            |
| E17  | The output isn’t perfect                                                  | Unfulfilled orders, low CPO’s quality                                 |
| E18  | Inhibition of production due to mechanical damage                         | Raw materials’ quality decrease, unachieved production target         |
| E19  | No quality checks are conducted during the process                        | Products quality below standard and rejected by consumers             |
| E20  | The defect in products yield                                              | Products are rejected by consumers, low selling price                 |
| E21  | Production activities aren’t done/stopped                                 | Raw materials accumulation, unachieved production target             |
| E22  | The demand can’t be fulfilled                                             | Consumer disclaimer                                                   |
| E23  | The waste is generated in large quantities                                | Environmental damage, waste treatment costs                           |
| E24  | The lack of product delivery capacity                                     | Late order fulfillment                                                |
| E25  | The lack of products in the distribution center                           | Opportunity lost                                                      |
| E26  | Delayed delivery of products to consumers                                 | Consumer disclaimer                                                   |
| E27  | Damage to the product during transportation                                | Products are rejected by consumers                                   |
| E28  | The quantity of raw materials is not suitable                             | Idle capacity                                                         |
| E29  | The stability of production is disrupted                                   | Idle capacity, unachieved production target                           |
| E30  | The cost of the products reprocessing                                     | Increasing of the total costs                                         |
| E31  | Rescheduling delivery                                                     | Sales delay, accumulating inventories                                 |
Appendix C. House of Risk 1 model result.

| Risk Event | S1 | Risk Agent | A1 | A2 | A3 | A4 | A5 | A6 | A7 | A8 | A9 | A10 | A11 | A12 | A13 | A14 | A15 | A16 | A17 | A18 | A19 | A20 |
|------------|----|------------|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| E1         | 4  | 9          | 9  | 1  | 1  | 9  | 3  |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E2         | 4  | 9          | 3  | 1  | 1  | 3  |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E3         | 4  | 3          | 1  | 3  | 3  | 1  | 1  | 3  | 1 |    |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E4         | 4  | 3          | 1  | 3  | 3  | 3  | 3  | 9  | 3  | 3  | 1  | 9  |     |     |     |     |     |     |     |     |     |     |     |     |
| E5         | 4  | 9          | 1  | 3  | 9  | 1  | 9  | 3  | 3  | 9  |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E6         | 4  | 9          | 9  | 1  | 9  | 9  | 3  | 9  | 9  | 3  | 3  |     |     |     |     |     |     |     |     |     |     |     |     |
| E7         | 4  | 3          | 9  | 1  | 9  |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E8         | 4  | 3          | 3  | 1  | 1  | 3  |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E9         | 4  | 3          | 3  | 1  |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E10        | 4  | 3          | 3  | 3  |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E11        | 4  | 3          |    |    | 3  | 3  |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E12        | 4  | 3          | 1  |    | 3  | 3  | 9  | 9  |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E13        | 4  | 3          | 1  | 3  |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E14        | 4  | 3          | 3  | 9  |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E15        | 4  | 3          | 3  | 3  | 3  | 1  | 9  | 3  | 1  |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E16        | 4  | 3          | 3  | 3  | 1  | 3  | 3  | 1  | 9  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E17        | 4  | 3          | 3  | 1  |    |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E18        | 4  | 3          | 3  | 3  | 3  |    |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E19        | 4  | 3          | 3  | 3  | 1  | 3  |    |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E20        | 4  | 3          | 3  | 3  | 3  | 1  | 1  |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E21        | 4  | 3          | 3  | 3  | 1  | 3  | 9  |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E22        | 4  | 3          | 3  | 3  | 1  | 3  | 3  |    |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |     |
| E23        | 4  | 3          | 3  | 3  | 1  | 3  | 3  | 3  |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |
| E24        | 4  | 3          | 3  | 3  | 1  | 3  | 3  | 3  |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |
| E25        | 4  | 3          | 3  | 3  | 1  | 3  | 3  | 3  |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |
| E26        | 4  | 3          | 3  | 3  | 1  | 3  | 3  | 3  |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |
| E27        | 4  | 3          | 3  | 3  | 3  | 3  | 3  | 3  |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |
| E28        | 4  | 3          | 3  | 3  | 3  | 3  | 3  | 3  |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |
| E29        | 4  | 3          | 3  | 3  | 3  | 3  | 3  | 3  |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |
| E30        | 4  | 3          | 3  | 3  | 3  | 3  | 3  | 3  |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |
| E31        | 4  | 3          | 3  | 3  | 3  | 3  | 3  | 3  |    |    |    |     |     |     |     |     |     |     |     |     |     |     |     |

ARP: 227 48 150 104 85 135 1224 360 1680 359 156 400 368 210 243 30 34.5 44 67 54
Rank: 8 16 11 12 13 18 2 5 1 6 10 3 4 9 7 20 19 17 14 15