Supply chain risk analysis of tempeh using modified failure mode and effects analysis

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Abstract. Risks and their associated sources of risks in the supply chain of tempeh vary either due to improper raw material handling, inappropriate production processes or improper product handling by salespersons. This research aims to identify the risks that occur in the tempeh supply chain at XYZ Company, conduct analysis and evaluate risks and provide a proposed risk mitigation strategy. Primary data were obtained through direct observation in the field and in-depth interviews of the actors involved in the tempeh supply chain. Identification of risks that occurred in the tempeh supply chain was conducted using SCOR approach. Risks were identified based on supply chain activities that occurred in the \textit{Plan, Source, Make, Deliver, Return} business processes. Risk analysis was carried out using Modified Failure Mode and Effect Analysis (FMEA) approach. The results showed that there are eleven risk events that must be taken into consideration for preventive program. The risk events are distributed in \textit{Plan} business process (3), \textit{Source} (1), \textit{Make} (4), \textit{Deliver} (2) and \textit{Return} (1). The preventive program for avoiding the risk events occurring should give precedence on controlling \textit{Fluctuating demand} (A1), \textit{Sudden order} (A4), \textit{Indiscipline of workers} (A14) and \textit{Close down of consumer’s business} (A18).

1. Introduction

Yogyakarta Special Region is one area that has a lot of tempeh industry. According to data from the Yogyakarta Industry and Trade Office, there are 505 tempeh industries in the Yogyakarta Special Region. The regency which has the largest number of tempeh industries is Bantul, accounting for approximately 262 tempeh industries. One of the tempeh industries in Bantul regency is XYZ Company which is located in Wiyoro, Bantul. Being operated since 1998, the company has a production capacity of 1 ton of soybeans per day and has become a national pilot of the tempeh industry. Nevertheless, the sustainability of the tempeh industry is inseparable from the risks. The risks and their associated sources of risks in the supply chain of tempeh at XYZ Company vary, such as fluctuations in the price of raw materials, unsold tempeh products and the presence of damaged tempeh products, either due to inappropriate production processes or improper product handling by salespersons. To overcome these risks, it is necessary to apply good supply chain management so that the activities of the tempeh supply chain can run smoothly. The company plays as the important supplier of tempeh to consumers in Bantul. Risk identification and mitigation strategies for the most dominant sources of risk are required. Based on the background of problems explained above, this study aims to identify the risks that occur in the tempeh supply chain at XYZ Company, conduct analysis, evaluate risks and provide a proposed risk mitigation strategy in the tempeh supply chain.

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system. The research findings can be used as the bases for making improvement of tempeh supply chain systems in Bantul regency.

1.1 Supply Chain Management

Basically, logistics is an orientation planning and framework for making a plan of product flows and information through business. Supply chain management is built based on this framework to obtain linkages and coordination among the processes of other entities in the flow chain such as suppliers, consumers, and the organization. One goal of supply chain management is to reduce or eliminate inventory buffering between organizations in the flow chain through the dissemination of information related to current demand and inventory levels [1].

According to [2], the scope of logistics ranges from management of raw materials to the delivery of finished products. Figure 1 shows that in logistics management, the fulfillment of consumer needs is carried out through coordination of material flows and information flows in a broad scope, not only within the scope of the organization and its operational activities but also involving consumers and suppliers in coordinating material and information flows. The scheme also shows that there is a concept of integration between activities to create a broad view of the system. Changes in one subsystem of a system will trigger changes in other sub-systems, which in some cases will change the entire logistics system. These changes can also occur in the allocation of costs in one sub-system that will affect the allocation of costs in other sub-systems. This supports Christopher's statement that in a logistics system a plan that is able to integrate each sub-system, from procurement related to suppliers, to organizational operations and distributions related to consumers is required.

![Figure 1. Logistics management process.](source)

1.2. Supply Chain Performance

One way to measure supply chain performance is to use SCOR (Supply Chain Operations Reference) method. The SCOR model is a process reference model for supply chain operations developed by SCC, Pittsburgh, PA[3]. SCOR has five important elements that integrates the process from supplier to customer where the process is in accordance with the company's operational strategy, material flows, works, and information. The five elements are Plan, Source, Make, Delivery and Return, as can be seen in figure 2 [3]:

![Figure 2. SCOR model.](source)
Risk management is a business that is rationally aimed at reducing the possibility of loss from the risks faced. Risk is not enough to be avoided, but must be dealt with in ways that can minimize the possibility of a loss. Risks can emerge at any time and preclude activities. Therefore, risks must be managed properly [5]. In relation to supply chain, risk is defined as any uncertainty that has the potential to negatively affect organizational performance [6]. Therefore, multiple aspects may be taken into account when choosing among techniques for managing risk in a project [7].

Failure Mode and Effect Analysis (FMEA) is a method used to identify the potential failure of a system, design or process and take actions that aim to prevent, eliminate or minimize the risk of failure [8]. FMEA provides an easy tool to determine which risk has the greatest concern and therefore an action is needed to prevent a problem before it arises [9]. Determination of Priority for risk preventive actions uses Risk Priority Number (RPN) which is a multiplication of the severity resulting from failure (S), probability of failure or occurrence (O) and control or detection program that have been carried out or planned (D). Nevertheless, the higher RPN does not indicate that a risk event should be given priority for preventive programs. [10] Suggest to pay more attention on its severity followed by its occurrence when prioritizing the preventive program.

An extension of the FMEA method specifically used to analyze the risk of a project is known as project risk FMEA or RFMEA [11]. The changes involve replacing the terms “failure mode” with “risk event”, "severity" with "impact" and "occurrence" with "likelihood". In addition, a new term risk score which is the product of likelihood and impact multiplication is used to describe the level of risk that occurs. FMEA was also adopted to deal with risks in the supply chain. The FMEA which is adopted to deal with risks in supply chain management shows its reliability in the process of managing risks through supplier assessment and selection [12].

In determining the priority of risk management [13] propose a different way. They do not consider the probability of occurrence of risk events but rather emphasize the probability of occurrence of risk agents. Given that a risk agent can cause more than one risk event, then aggregate risk potential from each risk agent is used. Risk analysis is carried out using the house of quality (HOQ) approach. House of risk 1 (HOR1) is used to determine priority of preventive actions on risk agents and use house of risk 2 (HOR2) to prioritize effective actions with reasonable resources.

In risk management, the application of FMEA at the planning stage and during the start of the project is very important to maintain a reliable workflow because it can anticipate risks or apply a framework for managing risks through different approaches. FMEA can also be used to establish a framework for implementing risk management practices and combine it with traditional constraints analysis and set future plans to make schedules more reliable and reduce vulnerability to planning failures [14].
2. Materials and Methods
The study was conducted on the tempeh supply chain system in XYZ Company, Wiyoro, Bantul regency, Yogyakarta special region in April - May 2017. Primary data were obtained through direct observation in the field and in-depth interviews of the actors involved in the tempeh supply chain, especially those who understood risks that occurred in the tempeh supply chain at XYZ Company. Identification of risks that occurred in the tempeh supply chain was conducted using SCOR approach. Risks were identified based on supply chain activities that occurred in the Plan, Source, Make, Deliver, Return business processes. Risk analysis was carried out by identifying the level of impact of a risk event (\(S_i\)), the probability or level of occurrence of a agent (\(O_j\)), and the ability to detect risk (\(D_i\)) with the Modified Failure Mode and Effect Analysis (FMEA) approach. The analysis steps are as follows:

1. Identify risk events that usually occur (\(E_i\))
2. Measure the level of severity of the risk events (\(S_i\))
3. Measure the level of detection that has been done to address the risks that occur (\(D_i\))
4. Identify all possible risk agents
5. Measure the probability or level of occurrence of the risk agents
6. Analyze the relationship between the risk events and the risk agents. Correlation value is measured by the following criteria:
   - strong correlation is weighted/marketed 9
   - moderate correlation weighted/marketed 3
   - Weak correlation is weighted/marketed 1
   - no correlation is weighted/marketed 0
7. Establish risk agents that have a strong influence on risk events
8. Calculate the probability or level of occurrence of risk events based on the probability of occurrence of strongly related risk agents using the following formula:
   \[
   O_i = \sum_{k=1}^{n_i} \frac{1}{n_i} x O_{i,k}
   \]
   Where:
   \(O_i\) = Occurrence of Risk Event i
   \(O_{i,j}\) = Occurrence of jth strongly related Risk Agent of Risk Event i
   \(n_i\) = Number of strongly related Risk Agent of Risk Event i
   \(O_{i,k}\) = Occurrence of kth strongly related risk Agent of Risk Event i
   \(i\) = index of Risk Event
   \(j\) = index of Risk Agent
   \(k\) = index of Strongly related Risk Agent of Risk Event
9. Calculate the risk priority number (RPN) of each risk event using the formula:
   \[
   RPN = S_i \times O_i \times D_i
   \]
   Where:
   \(S_i\) = Severity of Risk Event i
   \(O_i\) = Occurrence of Risk Event i
   \(D_i\) = Detection of Risk Event i
10. Determine the threshold for prioritizing the risk elimination or mitigation. In this case, based on the value guideline of severity/impact, occurrence/likelihood and detection provided by [11], the threshold is set to RPN of 125, resulting from the multiplication of level 5 of severity/impact, level 5 of occurrence/likelihood and level 5 of detection. Risk Events with RPN above or equal to 125 are subject to risk elimination or mitigation.
11. Determine the priority for controlling risk agents based on the most common risk agents strongly related with risk events that are subject to risk elimination or mitigation.

3. Results and Discussion

3.1 Company profile

XYZ Company has an average production of 500 kg of soybeans per day. The marketing of Tempeh spreaded through Bantul, Sleman and Yogyakarta city. The marketing of tempeh is conducted by 28 salesperson, 20 of which are adopting a yield sharing system of 10% while the remaining are adopting a yield sharing system of 15%. Each salesperson is free to sell tempeh to targeted consumers. The majority of consumers of tempeh from XYZ Company include food stalls, angkringen, vegetable stalls, tempeh sellers in the market, and fried snack sellers.

The selling system that is applied to angkringen, and food stalls is a break-up system where salesperson will get the entire proceeds from the sales of consumers even though not all tempeh marketed by consumers is completely sold. Nevertheless, not all consumers adopt the break-up system. Vegetable stalls and tempeh sellers in the market prefer adopting the consignment system, where salespersons will only receive money from sold tempeh and unsold tempeh will be returned by consumers to salespersons and then they return it to industry.

3.2. Risk event identification

After identifying supply chain activities using the SCOR approach the list of risk events can be seen in table 1.

Table 1. List of risk events and their respective business process.

| Code |
| Code | Risk Event | Business |
|------|------------|----------|
| E1   | No Conformity between Demand for product and its forecast | Plan |
| E2   | Sudden change of production plan |
| E3   | Sudden change of order plan by salesperson |
| E4   | Order mistakes |
| E5   | Discrepancy between the recorded and available stocks |
| E6   | Uncertain supplying time of raw material (soybeans) |
| E7   | Uncertain Quantity of raw material (soybeans) |
| E8   | Fluctuating price of raw material (soybeans) |
| E9   | Substandard quality of raw material (soybeans) |
| E10  | Deterioration of raw material (soybeans) |
| E11  | Non-conformance of packaging specification |
| E12  | Delayed production of tempeh |
| E13  | Product damage after production |
| E14  | Mistakes on packaging |
| E15  | Electricity shutdown |
| E16  | Mechanical breakdown on process equipment |
| E17  | Work Accidents |
| E18  | Non fulfilment of production target |
| E19  | Substandard quality of product (tempeh) |
| E20  | Product damage during delivery |
| E21  | Discrepancy between order and its delivery |
| E22  | Problem of on time delivery |
| E23  | Product return from consumers |
| E24  | Delayed product return (unsold tempeh) |
3.3. Risk agent identification

After identifying all risk events, risk agents were identified from the risk owner through interviews. From the interviews, 20 risk agents which caused 24 risk events in XYZ Company were obtained. Risk agents with their respective level of occurrence can be seen in Table 2.

Table 2. List of risk agents and their respective level of occurrence process.

| Code | Risk Agent                                                                 | Level of Occurrence (Oj) |
|------|-----------------------------------------------------------------------------|---------------------------|
| A1   | Fluctuating demand                                                          | 6                         |
| A2   | Non fulfilment of contract by suppliers                                     | 2                         |
| A3   | Long time of raw material storing                                          | 3                         |
| A4   | Sudden order                                                                | 9                         |
| A5   | Seasonal factor                                                             | 6                         |
| A6   | Problem electricity supply                                                  | 5                         |
| A7   | Improper product packaging                                                  | 4                         |
| A8   | Lack of surveillance                                                        | 5                         |
| A9   | Lack of maintenance of equipment                                            | 5                         |
| A10  | No Standard Operating Procedure                                             | 5                         |
| A11  | Improper raw material (soybeans) cleaning process                           | 5                         |
| A12  | Shorter time of raw material (soybeans) boiling process                     | 5                         |
| A13  | Slow fermentation process                                                   | 5                         |
| A14  | Indiscipline of workers                                                     | 6                         |
| A15  | Improper product handling by salesperson                                    | 4                         |
| A16  | Long distance of product delivery                                           | 8                         |
| A17  | Limited transportation media                                                | 3                         |
| A18  | Close down of consumer’s business                                           | 8                         |
| A19  | Disruption of system communication                                          | 4                         |
| A20  | Weather-related factor                                                      | 7                         |

Since there is possibility that a risk event is caused by more than one risk agent, or a risk agent causes more than one risk event then a correlation analysis among them is required. The result of analysis based on the responses of respondents during the survey can be seen in Table 3.

As can be seen from Table 3, not all the risk events such as E6: Uncertain supplying time of raw material (soybeans) and E7: Uncertain Quantity of raw material (soybeans) have strong correlation with the risk agents listed. Therefore, the rise of these risk events cannot be explained clearly what the causes are. As a consequence, these risk events are less prioritized in the preventive program.

Since this research did not measure the probability of occurrence of risk events, their level could be estimated by level of occurrence of their strongly related risk agents using the formula (1). The levels of occurrence, severity and detection of risk events, along with strongly related risk agents and associated RPN can be seen in Table 4.

3.4. Priority of preventive program

In order to determine priority for preventive program, the threshold of RPN was used. Using the value guidelines of severity, occurrence and detection proposed by [11], the threshold was set to RPN of 125 (resulting from setting levels of severity, occurrence and detection of 5 each). It can be seen from Table 4 that E1: No Conformity between Demand for product and its forecast, E2: Sudden change of production plan and E3: Sudden change of order plan by salesperson were the risk events subject to preventif program for Plan business process category. For Source business process, only E8: Fluctuating price of raw material that should be taken into consideration. In the Make business process category, there were 4 risk events that had to be considered i.e. E12: Delayed production of tempeh, E13: Product damage after production, E16: Mechanical breakdown on process equipment and E19: Substandard quality of product (tempeh). Deliver business process noted E20: Product
damage during delivery and E22: Problem of on time delivery while Return suggested E23: Product return from consumers for subjects of preventive programs.

**Table 3.** Correlation between risk event and risk agent.

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

“9” = Strong correlation between Risk Agent and Risk Event
“3” = Medium correlation between Risk Agent and Risk Event
“1” = Low correlation between Risk Agent and Risk Event
“0” = No correlation between Risk Agent and Risk Event

Preventive programs were focused on those strongly related risk agents. As can be seen from table 4, A1, A4, A14 and A18 are among the strongly related risk agents that dominantly caused the risk events to have RPN of above 125. Therefore, in order to anticipate or avoid risk events occurring, Fluctuating demand (A1), Sudden order (A4), Indiscipline of worker (A14) and Close down of consumer’s business (A18) must be taken into consideration and be put on priority of control. Important point to note, this research did not consider the costs of impact of risk events as well as the costs for controlling the risk agents. If information of costs is provided, it must be taken into consideration.

In some cases, the emersion of risk events cannot be explained clearly what the related risk agents are. Referring back to table 3, some risk events have no strong correlation with risk agents listed. Therefore, further investigation must be conducted to find other risk agents that strongly cause the related risk events to occur. [8] already explains that in a particular situation, a failure modes (risk events) can become an effect or a cause (risk agents) or vice versa. Therefore, to find the other strongly related risk agents, a bigger correlation matrix analysis involving the available risk events and risk agents in both rows and column would be helpful.
Table 4. Strongly related risk agents of risk events and levels of occurrence.

| Business Process | Risk Event (E) | Strongly related Risk agents | Level of Severity (Si) | Level of Occurrence (Oi) | Level of Detection (Di) | RPN |
|------------------|---------------|------------------------------|-----------------------|--------------------------|------------------------|-----|
| Plan             | E1            | A1, A4, A18                  | 6                     | 7                        | 5                      | 210^a |
|                  | E2            | A1, A4                       | 6                     | 8                        | 5                      | 240^a |
|                  | E3            | A1, A4, A18                  | 5                     | 7                        | 8                      | 280^a |
|                  | E4            | A1, A8, A14, A19             | 5                     | 5                        | 4                      | 100  |
|                  | E5            | A8, A14, A19                 | 4                     | 5                        | 3                      | 60   |
| Source           | E8            | A5                           | 6                     | 5                        | 6                      | 180^a |
|                  | E9            | A2                           | 6                     | 2                        | 3                      | 36   |
|                  | E10           | A3                           | 6                     | 3                        | 3                      | 54   |
| Make             | E12           | A14                          | 7                     | 6                        | 5                      | 210^a |
|                  | E13           | A14, A20                     | 9                     | 7                        | 7                      | 441^a |
|                  | E15           | A6                           | 2                     | 5                        | 2                      | 20   |
|                  | E16           | A9                           | 7                     | 5                        | 5                      | 175^a |
|                  | E17           | A14                          | 2                     | 6                        | 7                      | 84   |
|                  | E19           | A11, A12, A13, A14           | 5                     | 5                        | 5                      | 125^a |
| Deliver          | E20           | A15, A20                     | 9                     | 6                        | 3                      | 162^a |
|                  | E21           | A1, A4, A8                   | 5                     | 7                        | 3                      | 105  |
|                  | E22           | A13, A16                     | 8                     | 7                        | 3                      | 168^a |
| Return           | E23           | A18                          | 7                     | 8                        | 8                      | 448^a |

^aRisk Events with RPN equal or above the threshold (125)

^bRounded up/down to closest whole number

4. Conclusion

1) In the case of supply chain management of XYZ Company, there are eleven risk events that must be taken into consideration for preventive program. The risk events are distributed in Plan business process (3), Source (1), Make (4), Deliver (2) and Return (1). 2) The preventive program for avoiding the risk events occurring should give a precedence on controlling Fluctuating demand (A1), Sudden order (A4), Indiscipline of workers (A14) and Close down of consumer’s business (A18).

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