Analysis and strategy of supply chain risk mitigation using fuzzy failure mode and effect analysis (fuzzy fmea) and fuzzy analytical hierarchy process (fuzzy ahp)

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Abstract. PT XYZ is a company engaged in steel manufacturing and technical assistance. An example of the risk that occurs in supply chain activities in this company is that 8% of the total items experience delays in the Request Order (RO) to Purchase Orders (PO) in 2019. Currently, PT XYZ does not have supply chain risk management to identify and mitigate the risks that occur within the company. Therefore, this study aims to identify risks, determine priority risks and provide priority risk mitigation strategies that occur in the supply chain at PT XYZ. The method used is Supply Chain Operation Reference (SCOR), Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA) and Fuzzy Analytical Hierarchy Process (FAHP). The results of the study found 29 risk events and 4 priority risk events. Based on 4 prioritized risk events, the criteria which have the highest weight are the lack of the process of checking the raw material to be produced have a weight value 0.650 with the mitigation strategy carried out on the criteria is to adjust the demand documents and raw materials available. For the supplier performance criteria is not good to have a weight value 0.265 with the mitigation strategy carried out is conducting direct inspection to supplier company. The criteria for lack of coordination between companies and suppliers have a weight value 0.085 with the mitigation strategy carried out is to coordinate with suppliers. The lowest weighting criteria is the absence of project demand / tonnage forecasting processes with weights 0.000 and mitigation strategies carried out is to carry out project demand / tonnage forecasting processes.

1. Introduction

The company in conducting the activities of production of goods or services is always faced with various problems or risks that exist and appear continuously. Problems that arise usually result from within the company and from outside the company. The more growing manufacturing companies in the world, it will result in very tight competition for each company. The company can face all existing competition if all activities in the company are running smoothly.

At supply chain activities in the company there are certain risks that affect each of its activities. Risk is a potential event or occurrence, both predictable and unpredictable, that could cause a negative impact on achieving the company's vision and mission [1]. Risk management in supply chain management activities within the company is usually referred to as Supply Chain Risk Management (SCRM). The benefits of SCRM are to be able to identify and assess supply chain disruptions and can reduce the negative impact of supply chain performance [2].

PT XYZ is a company engaged in steel manufacturing and technical assistance from Emoto, Japan. PT XYZ was established on March 17, 1984 which is located in Argawana Village, Pulo Ampel, Serang, Banten. Production activities at this company are steel manufacture and technical assistance.
In running its production process, there must be risks that preclude the activity, especially in supply chain activities. As an example of the risk occurring in supply chain activity in PT XYZ is a delay in Request Order (RO) process until Purchase Order (PO). Request order is list material or raw material created by user who need material or raw material, while the purchase order is the list of materials or raw materials that have been ordered to the supplier. The process of request order until the purchase order is for 3 days. In 2019, PT XYZ made a purchase of 8334 items. There are 630 items or an 8% delay.

Many previous studies [3], [4], [5] are discussed aims to identify and minimize possible process failures occurred in one of the case point, some example are warehouse, logistics, or manufacturing, used risk analysis one of the method FMEA or Fuzzy AHP to identify and minimize the possible process failures. But not many studies have used the Fuzzy FMEA combined with Fuzzy AHP methods to solve the problem about of the risk occurring in supply chain activity as happened in PT XYZ is a delay in Request Order (RO) process until Purchase Order (PO).

At present, PT XYZ does not yet have supply chain risk management to identify and mitigate risks that occur within the company. Based on examples of risks contained in the company, it is necessary to conduct research to identify risks using the method of Supply Chain Operations Reference (SCOR). SCOR divides supply chain processes into 5 core processes, which are plan, source, make, deliver, and return. The next step is to analyze and evaluate risks using the Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA) method.

Fuzzy FMEA is the development of a conventional Failure Mode and Effect Analysis (FMEA) method which displays flexibility for uncertainty due to vague information and subjective preference elements used in evaluating the failure modes that occur [6]. The next step is to mitigate supply chain risk that occurs within the company using the Fuzzy Analytical Hierarchy Process (FAHP) method. Because AHP data is verbal data, it is possible that the data is still blurry and qualitative. Therefore, the step to quantify the data is the Fuzzy Analytical Hierarchy Process (FAHP) method. Fuzzy Analytical Hierarchy Process (FAHP) is an analytical method developed from AHP. FAHP is able to overcome weaknesses in criteria that have more subjective traits in the AHP method. This method is a technique used to overcome uncertainty in problems that have many answers [7].

The purpose of this study is to identify the risks that occur in the supply chain at PT XYZ, determine priority risks in the supply chain at PT XYZ and provide mitigation strategies against priority risks occurring in the supply chain at PT XYZ.

2. Methodology

Risk is a danger, a consequence that can occur as a result of an ongoing process or an upcoming occurrence. Risk is the potential occurrence of an event, whether predictable and unpredictable, that could cause a negative impact on achieving the company’s vision and mission [8].

Risk mitigation refers to minimizing risk after the risk arises. In other words, risk mitigation is a form of damage control. While the focus of risk mitigation is the action to be taken after the risk is realized, the company's risk mitigation strategies must be planned in advance, included or inserted in writing and are known by key people in an organization [9].

Supply Chain Management (SCM) is a series of activities including coordination, scheduling and control of procurement, production, inventory, and delivery of products or services to customers which includes daily administration, operations, logistics, and information processing ranging from customers to suppliers [10].

The Supply Chain Operations Reference (SCOR) model was developed to provide a method of self-assessment and comparison of supply chain activities and performance as a cross-industry supply chain management standard. This model presents a business process framework, performance indicators, best practices and technology to support communication and collaboration between supply chain partners, so as to increase the effectiveness of supply chain management and the effectiveness of supply chain improvement. SCOR divides supply chain processes into 5 core processes, which are plan, source, make, deliver, and return [11].
Fuzzy FMEA is the development of a conventional FMEA method that displays flexibility for uncertainty due to vague information and subjective preference elements used in evaluating the failure modes that occur [12]. There are 3 main stages in fuzzy FMEA, namely [13]:

1. Fuzzification, the process of converting risk factors to severity, occurrence and detection into fuzzy.
2. Rule evaluation, contains knowledge from experts regarding the interaction of error modes and the effects caused in the form of fuzzy rules “if then”.
3. Difuzzification, the process of creating ratings from fuzzy RPN to give the priority level of error mode

The following will explain the linguistic table and fuzzy number used to evaluate these factors and visualize the membership function of each factor. The table includes Table. 1 Fuzzy Severity, Table. 2 Fuzzy Occurrence, Table. 3 Fuzzy Detection and Table. 4 Fuzzy RPN [14].

| Table 1. Fuzzy Severity Scale |
|--------------------------------|
| Rating           | Fuzzy Number |
| Very low         | (3, 4, 5)    |
| Minor            | (2, 3, 4)    |
| Very minor       | (1, 2, 3)    |
| None             | (1, 1, 2)    |

(Source: Wang et al, 2009)

| Table 2. Fuzzy Occurrence Scale |
|--------------------------------|
| Rating               | Fuzzy Number |
| Very high (VH)       | (8, 9, 10, 10) |
| High (H)             | (6, 7, 8, 9)  |
| Moderate (M)         | (3, 4, 6, 7)  |
| Low (L)              | (1, 2, 3, 4)  |
| Remote (R)           | (1, 1, 2)     |

(Source: Wang et al, 2009)

| Table 3. Fuzzy Detection Scale |
|-------------------------------|
| Rating                | Fuzzy Number |
| Absolute uncertainty (AU)| (9, 10, 10) |
| Very remote (VR)       | (8, 9, 10)   |
| Remote (R)             | (7, 8, 9)    |
| Very low (VL)          | (6, 7, 8)    |
| Low (L)                | (5, 6, 7)    |
| Moderate (M)           | (4, 5, 6)    |
| Moderately high (MH)   | (3, 4, 5)    |
| High (H)               | (2, 3, 4)    |
| Very High (VH)         | (1, 2, 3)    |
| Almost certain (AC)    | (1, 1, 2)    |

(Source: Wang et al, 2009)

| Table 4. FRPN Value |
|---------------------|
| Category            | Parameter |


One of the disadvantages of AHP is that the judgment is too subjective and it is difficult to determine the weighting of each criterion. To deal with these weaknesses, a fuzzy AHP method was developed. Fuzzy AHP is a representation and existence of AHP by combining it with fuzzy set theory. The fuzzy concept used in the development of fuzzy AHP is Triangular Fuzzy Number (TFN). Triangular Fuzzy Number (TFN) is a fuzzy set theory that helps in measurements related to subjective judgment of humans using language or linguistics. The core of fuzzy AHP lies in paired comparisons which are described by the ratio scale related to the fuzzy scale. [15].

The following are the Fuzzy AHP stages [16]:
1. Arranging the Hierarchy of Problems. The hierarchy of problems is structured to assist the decision-making process by taking into account all the decision elements involved in the system.
2. Determination of Priorities. Compare the paired forms of all criteria for each hierarchy subsystem. Then calculate the eigenvalue and eigenvector.
3. Consistency

The formula of the consistency index is:

\[ CI = \frac{\lambda_{max} - n}{n - 1} \]  \hspace{1cm} (1)

Where:
CI = consistency index
\( \lambda_{max} \) = max eigenvalue
n = matrix order

If CI is zero (0), then the pairwise comparison matrix is consistent. The prescribed inconsistency limit is determined by using a Consistent Ratio (CR).

\[ CR = \frac{CI}{RI} \]  \hspace{1cm} (2)

Where:
CR = consistency ratio
RI = index random

If CR <0.1 then the value of pairwise comparisons on the criteria matrix is consistent.

4. AHP Fuzzification on Table 5, transform the AHP scale into Fuzzy numbers.
Table 5. Fuzzy Comparative Scale

| AHP Scale | Fuzzy Scale Level | Fuzzy Scale Inverse |
|-----------|------------------|---------------------|
| 1         | (1,1,1) If diagonal |
|           | (1,1,3) If other   | (1/3,1,1)           |
| 2         | (1,2,4)           | (1/4,1/2,1)         |
| 3         | (1,3,5)           | (1/5,1/3,1)         |
| 4         | (2,4,6)           | (1/6,1/4,1/2)       |
| 5         | (3,5,7)           | (1/7,1/5,1/3)       |
| 6         | (4,6,8)           | (1/8,1/6,1/4)       |
| 7         | (5,7,9)           | (1/9,1/7,1/5)       |
| 8         | (6,8,9)           | (1/9,1/8,1/6)       |
| 9         | (7,9,9)           | (1/9,1/9,1/7)       |

5. Calculates the value of fuzzy synthetic extent.

\[ S_i = \sum_{j=1}^{m} M \otimes \left[ \sum_{i=1}^{n} \sum_{j=1}^{m} M \right]^{-1} \]  

To obtain M, the formula used is:

\[ \sum_{j=1}^{m} M = \sum_{i=1}^{n} l, \sum_{i=1}^{n} m, \sum_{i=1}^{n} u \]

Where:
- \( M \) = TFN number
- \( m \) = number of criteria
- \( j \) = column
- \( i \) = row
- \( l \) = lower value
- \( m \) = medium value
- \( u \) = upper value

6. Compare the possible levels between fuzzy numbers.

\[ V(M_2 \geq M_1) = \begin{cases} 1, & \text{if } m_2 \geq m_1 \\ 0, & \text{if } l_1 \geq u_2 \\ \frac{(l_1 - u_2)}{(m_2 - u_2) - (m_1 - l_1)}, & \text{other} \end{cases} \]

7. Vector weight

\[ d'(A_j) = \min V(S_i \geq S_k) \]

\[ W' = (d'(A_1), d'(A_2), ..., d'(A_n)) T \]

8. Normalization
\[ W = \left( d(A_1), d(A_2), \ldots, d(A_n) \right)^T \]
\[ d(A_n) = \frac{d'(A_n)}{\sum_{i=1}^{n} d'(A_n)} \]

3. Result And Discussion

Based on the identification of risk events using the SCOR method there were 29 supply chain risk events that occurred at PT XYZ. The following Table. 6 and Table 7 are the result of risk measurement using the Fuzzy FMEA method with Matlab software:

| Major Process | Risk Event Description                                      | Code | Severity | Occurrence | Detection | FRPN    | Category |
|---------------|-------------------------------------------------------------|------|----------|------------|-----------|---------|----------|
| Plan          | Determination of the number of project requests/tonnage is incorrect | E1   | 8        | 4          | 8         | 400     | MH       |
|               | Forecasting projects are not as planned                     | E2   | 8        | 4          | 5         | 208,175 | L-M      |
|               | Project completion is not on time                            | E3   | 9        | 2          | 8         | 208,175 | L-M      |
|               | There is no project progress report                          | E4   | 8        | 2          | 9         | 208,175 | L-M      |
|               | Overtime is not well planned                                 | E5   | 8        | 3          | 8         | 208,175 | L-M      |
| Source        | Raw materials that reject from suppliers                    | E6   | 10       | 3          | 9         | 300     | M        |
|               | Raw materials do not match the order                         | E7   | 8        | 3          | 9         | 208,175 | L-M      |
|               | Error choosing suppliers                                     | E8   | 7        | 3          | 9         | 208,175 | L-M      |
|               | Error in inspection process when item arrives                | E9   | 9        | 2          | 9         | 208,175 | L-M      |
|               | Supplier cannot fulfill order quantity                      | E10  | 7        | 2          | 8         | 208,175 | L-M      |
|               | Raw materials available in the warehouse can no longer be used | E11  | 6        | 2          | 8         | 133,155 | L        |
|               | Late issuance of purchase order letters                      | E12  | 7        | 2          | 8         | 208,175 | L-M      |
| Make          | Delay in production schedule                                | E13  | 7        | 4          | 4         | 133,155 | L        |
|               | Damage to the production machine                             | E14  | 5        | 3          | 5         | 24.5    | VL       |
|               | Raw materials that are not available when they will be produced | E15  | 8        | 5          | 6         | 300     | M        |
|               | Occupational accidents                                       | E16  | 8        | 2          | 4         | 75      | VL-L     |

Table 7. Result of Supply Chain Risk Defuzzification
| Major Process | Risk Event                                                                 | Code | Severity | Occurence | Detection | FRPN     | Category |
|---------------|----------------------------------------------------------------------------|------|----------|-----------|-----------|----------|----------|
| Make          | The existence of reject products                                          | E17  | 9        | 3         | 5         | 133,155  | L        |
|               | Lack of raw materials                                                     | E18  | 7        | 5         | 5         | 208,175  | L-M      |
|               | Lack of labor in the production section                                   | E19  | 6        | 3         | 3         | 75       | VL-L     |
|               | The production process is not going well because of additional projects   | E20  | 6        | 5         | 5         | 133,155  | L        |
| Deliver       | Delay in product delivery to customers                                    | E21  | 3        | 4         | 8         | 75       | VL-L     |
|               | Delay arrival of raw materials from suppliers                            | E22  | 3        | 3         | 7         | 24,5     | VL       |
|               | The product is damaged while on the trip                                  | E23  | 2        | 2         | 9         | 24,5     | VL       |
|               | Limitations on transportation equipment for product delivery              | E24  | 2        | 2         | 9         | 24,5     | VL       |
| Return        | There are additional costs when the process of returning raw materials to | E25  | 3        | 4         | 7         | 75       | VL-L     |
|               | suppliers                                                                  |      |          |           |           |          |          |
|               | Delay in the arrival of raw materials from suppliers                      | E26  | 7        | 4         | 7         | 300      | M        |
|               | Suppliers who do not receive returned raw material                        |      |          |           |           |          |          |
|               | Delay in the process of returning reject products from customers          | E27  | 3        | 2         | 9         | 75       | VL-L     |
|               | Delay in the process of sending replacement products to customer          | E28  | 3        | 3         | 8         | 24,5     | VL       |
|               | Delay in the process of sending replacement products to customer          | E29  | 4        | 3         | 7         | 75       | VL-L     |

The next stage is the risk evaluation stage using pareto diagrams and categorization. Here Figure 1. is a pareto diagram of supply chain risk:
Based on the Pareto risk of supply chain diagrams, categories can be divided based on the 80/20 priority value classification, where the priority of supply chain risk is around 80% of the problems caused by 20% of the causes. There are 16 priority risks included in the 80% are E1, E15, E26, E6, E10, E12, E18, E2, E3, E4, E5, E7, E8, E9, E11 and E13.

Then categorize the data into high categories based on 16 risk events. The following Table 8. is the results of determining supply chain risk categories:

**Table 8. Penentuan kategorisasi risiko**

| No. | Code | FRPN | No. | Code | FRPN |
|-----|------|------|-----|------|------|
| 1   | E1   | 400  | 9   | E9   | 208,175 |
| 2   | E2   | 208,175 | 10  | E10  | 208,175 |
| 3   | E3   | 208,175 | 11  | E11  | 133,155 |
| 4   | E4   | 208,175 | 12  | E12  | 208,175 |
| 5   | E5   | 208,175 | 13  | E13  | 133,155 |
| 6   | E6   | 300  | 14  | E15  | 300 |
| 7   | E7   | 208,175 | 15  | E18  | 208,175 |
| 8   | E8   | 208,175 | 16  | E26  | 300 |

Total 3648.06
Average 228.004
Standard Deviation 66.862
Low Category $X < 161.142$
Moderate Category $161.142 \leq X < 294.866$
High Category $X \geq 294.866$

Calculation example:

High category
$X \geq (\mu +1.0\sigma)$
$= X \geq (228,004 + (1 \times 66,862))$
$= X \geq 294,866$
The risks included in the high category are the determination of the number of project requests/inappropriate tonnage (E1), raw materials that reject from suppliers (E6), raw materials that are not available when produced (E15) and late arrival of raw materials replacing from suppliers (E26).

Then look for the causes of risk for 4 risk events to make it easier to mitigate risk. For the risk of determining the number of project requests / inappropriate tonnage (E1) the cause is the absence of a forecasting process carried out by related parties regarding project demand / tonnage for each month. In the event of risk of raw materials that reject from suppliers (E6) the cause is that supplier performance is not good. In the event of a risk of raw materials not available when it is being produced (E15) the cause is the lack of a process for checking raw materials to be produced. Then for the incident of the risk of late arrival of raw materials in lieu of supplier (E26) the cause is a lack of coordination between the company and the supplier.

The next step is to carry out supply chain risk mitigation strategies using the FAHP method based on 4 risk causes. In Figure 2, is the result of weighting criteria and subcriteria that have been determined and assessed by the parties concerned.

The criteria are filled with the causes of risk and the subcriteria section is filled with risk mitigation steps. On the criteria for the absence of a project / tonnage demand forecasting process, the mitigation

![Figure 2. Criteria and subcriteria weighting](image-url)
strategy undertaken is to carry out the project demand / tonnage forecasting process and brainstorm with the parties concerned. On the criteria of supplier performance is not good, the mitigation strategy that is carried out is evaluating supplier performance and conducting direct inspections to supplier companies. On the criteria for the lack of checking the raw material to be produced, the mitigation strategy undertaken is adjusting the demand documents and available raw materials and material controls. On the criteria for lack of coordination between companies and suppliers, the mitigation strategy undertaken is evaluating supplier performance and coordinating with suppliers.

On the criteria and subcriteria that have been determined, then the next step is to calculate consistency. The criteria for supply chain mitigation strategies have a CR value of 0.075. This CR value is less than 0.1, so the pairwise comparison matrix criteria are consistent. In the sub-criteria of the absence of project demand / tonnage demand forecasting processes, supplier performance sub-criteria are not good, sub-criteria lack of raw material checking process to be produced and sub-criteria lack of coordination between company and supplier have a CI value of 0, then pairwise comparison criteria are consistent.

Based on Figure 3, it can be seen that the criteria which have the highest weight are the lack of the process of checking the raw material to be produced with a weight = 0.650. The mitigation strategy carried out on the criteria is the lack of the process of checking raw materials to be produced is to adjust the demand documents and raw materials available with weights = 1. For the supplier performance criteria is not good to have a weight value = 0.265 with the mitigation strategy carried out is conducting direct inspection to supplier company with weight = 0.621. The criteria for lack of coordination between companies and suppliers have a weight value = 0.085 with the mitigation strategy carried out is to coordinate with suppliers with weights = 1. The lowest weighting criteria is the absence of project demand / tonnage forecasting processes with weights = 0,000 and mitigation strategies carried out is to carry out project demand / tonnage forecasting processes with weights = 1.

4. Conclusion

Based on the results of the research that has been done, the conclusions are as follows:

1. Risk identification occurring in the supply chain at PT XYZ are 29 risk events. In the plan process there are 5 risk events, the source process has 7 risk events, the make process has 8 risk events, in the deliver process there are 4 risk events and in the return process there are 5 risk events.

2. Priority risks in the supply chain at PT XYZ are 4 risk events, which are the risk of determining the number of project requests/inappropriate tonnage (E1), the risk of raw materials rejecting suppliers (E6), the risk of raw materials not available when they are to be produced (E15) and the risk of late arrival of raw materials in lieu of supplier (E26).

3. Mitigation strategies carried out on priority risks that occur in the supply chain at PT XYZ, namely for priority risk causes the lack of raw material checking process to be produced is to adjust the demand documents and available raw materials with a weight value of one (1). The mitigation strategy for the cause of risk is the supplier's poor performance priority is to conduct an inspection directly to the supplier company with a value of 0.621. The mitigation strategy that causes the risk of lack of coordination between companies and suppliers is coordinating with suppliers with a weight value of one (1). The priority risk mitigation strategy for the absence of a project demand / tonnage forecasting process is to carry out the project demand / tonnage forecasting process with a weighting value of one (1).

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