Supply Chain Risk Management Analysis using the Development of Fuzzy Reasoning Methods and Analytical Network Process (ANP) at Wooden Toys Industries

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Abstract. The supply chain is the relationship between material flows or services, money flow and information ranging from suppliers, producers, distributors, warehouses, retailers to customers. The smooth flow of material in the supply chain affected in the fulfillment of customer needs. If the problem occurs, it caused losses and risks. To minimize risks, it can be handled with Supply Chain Risk Management. This research was conducted in the supply chain in Wooden Toys Industries by identifying risks using the Fuzzy Reasoning method to calculate the amount of opportunity and impact that would arise if the risk occurred. To reduce the opportunity and impact of risk, a mitigation strategy is needed to consider and can be done using the Analytical Network Process method. Followed the results, the competitor’s moves have a large chance and risk. Thus, risk mitigation can be proposed is necessary to conduct market observations and identify competitors at (31.3%).

Keywords: analytical network process, fuzzy reasoning, supply chain, supply chain risk management, risk.

1. Introduction
In the increasingly broad industrial world, where in an industry there are activities to convert raw materials into finished goods. In making changes from raw materials to finished goods, the supply chain must be able to be controlled so that the relationship between material flows or services, cash flow and information ranging from suppliers, producers, distributors, warehouses, retailers to end customers is able to meet the needs or demands with smoothly. The role of the supply chain in principle is to add value to the product, by moving it from one location to another, or by making changes to it [1]

Where every activity carried out by a company will not be separated from unplanned events or uncertainties that can affect the flow of materials or components in the supply chain. Unplanned events or uncertainties can be said to be risks that will occur [2]. Risk is an operational inhibiting factor in the supply chain, where risks can occur from upstream, factory, distribution and downstream of the distributor. The potential risk if it really happens will certainly have an impact on the performance of
the company's supply chain management [3], from these risks can lead to losses; risks cannot be avoided but can be minimized or eliminated by handling appropriate risks. Handling for risks that have the potential to occur in the supply chain can be handled with Supply Chain Risk Management (SCRM). SCRM is a systematic identification, assessment and mitigation of potential disturbances in logistics networks with the aim of reducing the negative impact on the performance of the supply chain network [4]. By using SCRM, the risks that have potential can be classified. The industry that has significant impact in national economic development is small and medium industries like a wooden toy companies where focused on children's toys, made from wood. They are also has risks and need some approximation to mitigate their risks. SCRM can be used to answer that problem by developing Fuzzy reasoning (FR) and Analytical Network Process (ANP). FR is a systematic tool to deal with qualitative and quantitative data and information that arise in an activity [5]. This method is used to find out the magnitude of the opportunity and the impact of risk. Furthermore, Analytical Network Process (ANP) is an extended method from Analytical hierarchy Process (AHP) which can be used for relative measurement and useful to reduce the ratio of priority from individual ratio [6]. Thus, ANP is used to determine a mitigation strategy that has a large percentage in order to minimize the risks. Wooden Toy Industry is industry small and medium where focused on children's toys

2. Methods
In the first stage, it is done by identifying risks that have an emerging opportunity and a large impact using the fuzzy reasoning (FR) method, in the first FR method, namely identifying risks in the supply chain in a wooden toy company by means experts who have been determined, identification of risks in terms of factors and variables, then after understanding what risks occur in a wooden toy company, the factors and risk variables are described in the form of a hierarchy. The stages in this study can be seen in figure 1.

![Figure 1. Fuzzy reasoning and ANP method flowchart](image-url)

To assess the factors and risk variables, expert judgment is needed, where there are 3 experts who have different backgrounds. Expert weighting is carried out based on their respective positions,
background and expertise. To measure the FI phase, an assessment of the likelihood of an existing variable is needed, the assessment is done by linguistic variables which are then translated into fuzzy grouping, then, the comparison between sub-factors or risk variables in each index factor influences them. The calculation is done by comparison, which is then carried out with aggregated STFNs on each risk variable. And after aggregating STFN on each risk variable then calculate the overall FI weight. To get the final value of FI can be done using equation (1) to equation (9).

\[
\mu_A(x) = \begin{cases} 
\frac{x-a^1}{a^m-a^1} & \text{for } a^1 \leq x \leq a^m \\
\frac{a^n-x}{a^n-a^m} & \text{for } a^m \leq x \leq a^n \\
0 & \text{otherwise}
\end{cases}
\] (1)

\[
S_i^* = S_i^* \otimes c_1 \oplus S_i^2 \otimes c_2 \oplus \ldots \oplus S_i^m \otimes c_m
\] (2)

\[
a_{ij} = \frac{a_{ij1} \otimes c_1 + a_{ij2} \otimes c_2 + \ldots + a_{ijm} \otimes c_m}{\sum_{r=1}^{m} a_{ijr}}
\] (3)

\[
a_{ij} = a_{ij} + 2(a_{ij}^m + a_{ij}^n) + a_{ij}^m
\] (4)

\[
A = a_{ij} = \begin{bmatrix} F_1 & F_2 & \ldots & F_n \\ 1 & a_{12} & \ldots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \ldots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \ldots & 1 \end{bmatrix}, i, j = 1, 2, \ldots, n
\] (5)

\[
w_i = \frac{1}{n} \sum_{j=1}^{n} \sum_{k=1}^{n} a_{kj}^i, i, j = 1, 2, \ldots, n
\] (6)

\[
w_i' = w_i \prod_{l=1}^{n} w_{\text{section}}^l
\] (7)

\[
FI^* = \sum_{i=1}^{n} S_i^* w_i'
\] (8)

Information:

\[
S_i^* = \text{Fuzzy aggregated}
\]

\[
a_{ijn} = \text{Corresponding STFN scale of Fi}
\]

\[
c_n = \text{CFs allocated to expert}
\]

\[
a_{ij} = \text{Aggregated Fuzzy scale of fuzzy}
\]

\[
w_i = \text{Weight FI}
\]

\[
w_i' = \text{Final weight of FI}
\]

\[
FI^* = \text{Fuzzy of FI}
\]

\[
F = \text{Risk factor in one section}
\]

The first measurement of RL and RS is done by conducting an expert study of the police from the experience. The assessment is carried out with linguistic variables, after being carried out further to correct the STFN and carry out the STFN aggregate. To get the RL and RS values can be calculated using formulas (10) and (11).

\[
RL^* = RL_1^* \otimes c_1 \oplus RL_2^* \otimes c_2 \oplus \ldots \oplus RL_m^* \otimes c_m
\] (10)

\[
RS^* = RS_1^* \otimes c_1 \oplus RS_2^* \otimes c_2 \oplus \ldots \oplus RS_m^* \otimes c_m
\] (11)

And for fuzzy interface phase, it begins by converting aggregated STFN from each risk factor into a fuzzy set. To convert aggregated STFN that is by taking the intersection value between STFN and MF whose parameters are interconnected, then defuzzification is done to convert the fuzzy result into a suitable numerical value that can represent RM. To get a combination of RM* it can be done with equation (12) and from the combination results obtained the Risk Magnitude (RM*) with equation (13) to (15). Then do the conversion into the fuzzy set to find out the percentage of the value of RM * with equation (16).

\[
R^k = a_{FI}, \text{ dan } RL^* = a_{RL}, \text{ and } RS^* = a_{RS}
\]

Next RM* is \(a_{RM}^k\)

\[
R^k = a_{FI}, \text{ dan } RL^* = a_{RL}, \text{ and } RS^* = a_{RS}
\]

(12)
\[ \mu_R^k(x, y) = \mu_{F_1^*}(x_1) \land \mu_{R_L^*}(x_2) \land \mu_{R_S^*}(x_3) \land \mu_{R_M^*}(y) \]  
\[ \mu_R(\chi, y) = \bigvee_{K=1}^{K_0} R^k(\chi, y) \]  
\[ \text{RM}^* = \text{RP}^* \circ R(\chi, y) \]  
\[ \text{RM} = \frac{\sum_{i=1}^{n} y_i \mu_{RM^*}(y'_i)}{\sum_{i=1}^{n} \mu_{RM^*}(y'_i)} \]  

Information:
\( \mu_{F_1^*} = \) Denote the universe of FI*, RL*, RS* dan RM*
\( \mu_R(\chi, y) = \) Output fuzzy MF after aggregation

In the second stage, to mitigate the risks that has big opportunities and impacts by using the Analytical Network Process method. In the submission of a strategy to minimize risk, a literature study is conducted and the interview is returned to the expert and evaluates the comparative matrix of the proposed strategies. After getting an assessment from an expert, the 3 expert assessment results are converted into1 matrix using the geometric mean equation that is in equation (17).

\[ \text{Geometric Mean} = \sqrt[n]{x_1 \times x_2 \times \ldots \times x_n} \]  

From these inputs can find out how consistent the expert answers to the comparative matrix questionnaire that has been given, if consistent (<0.1) then the calculation can proceed to find out the final percentage of each alternative, if it is not consistent (> 0.1) then an expert reassessment against alternative strategies proposed in the form of a comparative matrix. The consistency calculation can be done using equation (18) and equation (19).

\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \]  
\[ CR = \frac{CI}{RI} \]

3. Result and Discussion

3.1 Risk Analysis with Fuzzy Reasoning Method

3.1.1 Prelaminar Phase

For the initial step in this phase is risk identification, risk identification is carried out by means of knowing or determining the risk of what often happens or has the opportunity to occur in the supply chain of a wooden toy company. Risk identification was carried out with a literature study [7] and interviews with experts, after identifying 25 risk variables were grouped into 6 factors.

| Risk Factor | Risk Variable |
|-------------|---------------|
| Demand      | Market saturation | Information |
|        | Competitor moves | Information delays |
|        | Delay in delivery to customer | Wrong choice of communication |
|        | Forecast error | Capacity inflexible |
|        | Macroeconomic uncertainty | Design change |
| Environment | Nature disasters | Operation |
|        | Social uncertainty | Disruption in production |
|        | Policy uncertainty | Inventory risk |
|        | Cost/price risk | Variability in production process |
| Finance    | Exchange rate risk | Dependancy on single supplier |
|        | Breakdown of IT infrastructure | Inflexibility of supplier |
| Information| Distorted information | Supply |
|        | Inadequate information security | Poor delivery performance |

Supplier poor quality |
Supplier bankruptcy |
This stage begins with determining the value of the Contribution Factor to the expert who is the source of the research. Values are determined based on their position, background and expertise [7]. Table 1 is the allocation of CF values of each expert.

### Table 2. CF of each expert

| Expert | Background Expert | CFs |
|--------|-------------------|-----|
| E1     | CEO of Wooden Toys Industries | C1 = 0.5 |
| E2     | Finance that deals directly with suppliers and overseas production | C2 = 0.25 |
| E3     | Production is related to raw materials and runs in process | C3 = 0.25 |

For membership function index factor, risk likelihood, and risk severity are illustrated in Figure 2, while for risk magnitude is illustrated in Figure 3.

### 3.1.2 FI, RL and RS Measurement Phase

In the initial stage, which is the measurement of FI weight, for that purpose, an assessment of each risk is carried out and translates into fuzzy grouping from the assessment using linguistic variables which then make comparisons between risk variables in each of the index factors that influence it and then aggregated STFNs on each risk variable. And after aggregating STFN on each risk variable then calculate the overall FI weight. To determine the value of the FI, a calculation is made using equation (1) to equation (9).

### Table 3. Measurement of FI, RL and RS

| Risk Factor | FI*            | RL*            | RS*            |
|-------------|----------------|----------------|----------------|
| Demand      | (1.93091, 3.425524, 3.425524, 4.60216) | (4.375, 6.875, 6.875, 9.375) | 3.75, 6.25, 6.25, 8.75 |
| Environment | (0.774526, 1.600278, 1.600278, 3.335869) | (3.75, 6.25, 6.25, 8.75) | (6.25, 8.75, 8.75, 10.0) |
| Finance     | (1.07181, 2.296736, 2.296736, 3.368546) | (3.75, 6.25, 6.25, 8.75) | (4.375, 6.875, 6.875, 9.375) |
| Information | (1.819194, 4.004576, 4.004576, 5.782933) | (2.5, 5.0, 5.0, 7.5) | (3.75, 6.25, 6.25, 8.125) |
| Operation   | (1.533914, 3.417977, 3.417977, 5.221739) | (4.375, 6.875, 6.875, 9.375) | (5.0, 7.5, 7.5, 10.0) |
| Supply      | (1.934435, 3.638779, 3.638779, 5.020997) | (1.875, 4.375, 4.375, 6.875) | (3.75, 6.25, 6.25, 9.375) |
For the measurement of RL and RS the first is done by conducting an assessment by an expert on the possibility of occurrence and the severity of the risk. Assessment is carried out with linguistic variables, after the assessment is carried out then converts the assessment to the STFN value to do the STFN aggregate calculation from the assessment results. To get the RL and RS values can be calculated using equations (10) and (11).

3.1.3 Fuzzy Inference Phase
At this stage, the first step is to convert aggregated STFNs FI, RL and RS into fuzzy sets, where to convert aggregated STFN by taking the intersection value between STFN and Membership Function (MF) whose parameters are interconnected, then defuzzification is performed to convert fuzzy results be a suitable numeric value that can represent RM. Fuzzy inference system produces mapping between input parameters FI *, RL *, RS * and RM * output. To do the RM * output value it can be done with equation (12).

The following are the results of STFN conversion into the fuzzy set for each risk factor.

| Risk Factor | FI* | RL* | RS* |
|-------------|-----|-----|-----|
| Demand      | (Poor, 0.7724), (Poor, 3.6298), (Fair, 0.8409) | (Medium, 0.75), (Medium, 0.75), (Medium, 0.75) | (Medium, 0.5), (High, 0.5), (High, 0.5), (High, 0.5) |
| Environment | (Very Poor, 0.6902), (Poor, 0.6401), (Poor, 0.6657) | (Medium, 0.5), (Medium, 0.5), (Medium, 0.5), (High, 0.5) | (Medium, 0.5), (High, 0.5), (Very High, 0.5) |
| Finance     | (Poor, 0.9187), (Poor, 0.9187) | (Low, 0.5), (High, 0.54), (High, 0.54), (High, 0.5) | (Medium, 0.75), (High, 0.75), (High, 0.75), (Very High, 0.75) |
| Information | (Poor, 0.6018), (Fair, 0.6018), (Fair, 0.6868) | (Low, 1.0), (Medium, 1.0), (Medium, 1.0), (Medium, 1.0) | (Low, 0.50, (Medium, 0.5), (Medium, 0.5), (High, 0.75)) |
| Operation   | (Very Poor, 0.3864), (Poor, 0.6328), (Fair, 0.3672), (Poor, 0.3864), (Fair, 0.9113) | (Medium, 1.0), (Medium, 1.0), (Medium, 1.0), (Very High, 1.0) | (Medium, 0.75), (High, 0.75), (High, 0.75), (High, 0.75) |
| Supply      | (Poor, 0.7738), (Poor, 0.5445), | (Low, 0.75), (Medium, 0.75), (Medium, 0.75), (High, 0.75) | (Low, 0.5), (Medium, 0.5), (Medium, 0.5), (Very High, 1.0) |
|             | (Fair, 4.555), (Fair, 0.9916) | |

After converting, the next step is to form a combination of the conversion results with the "if-then-rules" function, the number of rules can be known by multiplying the number of FI, RL, and RS. From the combination results obtained the results of Risk Magnitude (RM*) with equations (13) to (15). Then do the conversion into the fuzzy set to find out the percentage of the value of RM * with equation (16).

After calculating to get the RM value, the RM value is converted into fuzzy sets by taking the intersection between lines in the figure 3 graph. Because the RM value on each risk factor has the same results, then to find out the risks that have great opportunities and big impacts can be seen in the FI* value on the risk variable, then the competitor moves is obtained with the magnitude of the impact that arises is a major of 75% and a minor of 25%.

3.2 Mitigation Strategy with Analytical Network Process

3.2.1 The Proposed Alternative
To make a good strategy to minimize the risk of competitor moves, there are 6 strategies such as The strategies are market observations and recognizing opportunities (S1), Creating a different product,
highlighting the superiority of products (S2), Highlighting the superiority of products (S3), Learning competitors’ strengths and weaknesses (S4), Competitive price offerings (S5), and Creating events for product promotion (S6). For input calculations geometric mean of experts are done by using equation (17) can be seen in Table 5.

Table 5. Aggregated of experts judgment using geometric means

| Strategy for Competitor Moves | S1   | S2   | S3   | S4   | S5   | S6   |
|-----------------------------|------|------|------|------|------|------|
| S1                          | 1.00 | 1.91 | 1.33 | 2.47 | 4.22 | 5.13 |
| S2                          | 0.52 | 1.00 | 1.91 | 3.27 | 3.27 | 3.27 |
| S3                          | 0.75 | 0.52 | 1.00 | 1.91 | 3.27 | 3.56 |
| S4                          | 0.41 | 0.31 | 0.52 | 1.00 | 0.75 | 2.76 |
| S5                          | 0.24 | 0.31 | 0.31 | 1.33 | 1.00 | 1.33 |
| S6                          | 0.19 | 0.31 | 0.28 | 0.36 | 0.75 | 1.00 |

3.2.2 Data Consistency Analysis
In this stage calculated whether the experts' judgment is consistent or not. For this reason, the step is to find out the Consistency Ratio (CR) value by calculating the Consistency Index (CI) previously. The CI used equation (18) and the CR used equation (19) as be seen in examples below.

\[
CI = \frac{\lambda_{max} - n}{n - 1} = \frac{6.1951}{6-1} = 0.0390
\]

\[
CR = \frac{CI}{RI} = \frac{0.0390}{1.24} = 0.0315
\]

The results obtained CR value <0.1, it can be said that the expert judgment is consistent or value according to the Saat Saaty statement, that CR is recommended to have a value equal to 0.1 [10].

3.2.3 Priority of Strategy
To find out which strategies have priority to recommend can be seen from the percentage results that have the highest number. The strategies are market observations and recognizing opportunities (31.30%), Creating a different product, highlighting the superiority of products (25.20%), Highlighting the superiority of products (19.70%), Learning competitors’ strengths and weaknesses (10.10%), Competitive price offerings (8.10%), Creating events for product promotion (5.60%). So we can know the strategies the market observations and recognizing opportunities that have the largest percentage of 31.3%.

4. Conclusion
Based on the results of research and analysis, obtained the results of the risks in the Wooden Toys Industries consists of 6 risk factors, where each risk factor has its own risk variables. For demand risk factors there are 4 risk variables, namely late delivery to customers, forecast errors, market saturation, and competitor moves. In environmental risk factors there are 4 risk variables, namely macroeconomic uncertainty, natural disasters, policy uncertainties, and social uncertainties. On financial risk factors there are 2 risk variables, namely cost/price risk, and exchange rate risk. In information risk factors there are 5 risk variables, namely breakdown of IT infrastructure, information distortion, inadequate information security, information delays, and wrong communication options. In operational risk factors there are 5 risk variables, namely capacity inflexible, design changes, disruption in production, inventory risk, and variability in production process. And on operational risk factors there are also 5 risk variables, namely dependence on single suppliers, inflexible of supplier, poor delivery performance, supplier poor quality, and supplier bankruptcy.
And based on calculations using the fuzzy reasoning method, the results show that the risk variables of the competitor moves in the risk factor of demand are more likely to occur and have a large impact. From these results, mitigation strategies are carried out using analytical network process methods with the help of super decision software and the results of market observation strategies and recognizing good competitors are carried out to minimize the risk of competitor moves. This research is an enrichment of the method or has not been implemented. Therefore, there are no significant implications of the results.

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