Fuzzy Reasoning House of Risk to Manage Supply Chain Risk in Wooden Toys Industries

Widya Nurcahayanty Tanjung[#1], Selma Intan Praditya Sari Himawan[#2], Syarif Hidayat[#3], Endang Ripmiatin[*4], Selvy Sekar Asti[#5], Ratu Siti Khodijah[#6], Saaras Ayu Atikah[#7]

[#] *Industrial Engineering, Faculty of Science and Technology, Al Azhar Indonesia University, Indonesia*
[*] *Informatics Engineering, Faculty of Science and Technology, Al Azhar Indonesia University, Indonesia*
[1]widya@uai.ac.id, [2]himawanselma@gmail.com

Abstract*— The research was done in wooden toy industry which have complex supply chain. Because of their complexity, there will be a lot of risks attached to it. Risks factor which can be identified in this business are out of stock product and human factor. To assess the risks, a new method is developed to eliminate subjective factors from decision makers. The proposed method is Fuzzy Reasoning House of Risk (FHOR). This method is combination of fuzzy reasoning risk assessment model and house of risk which can be contribute to enrich risk assessment methodology. House of Risk Method is used to identify the most potential risk agents, while the fuzzy reasoning risk assessment model is used to determine the risk severity by risk agents. Based on the analysis, it is found that risk agent stock out of the product is the most potential risk agent in this industry. To reduce the impact, mitigation strategies are suggested for stock out product risk agents in warehouse are flexible supply base, safety stock, internal coordination, as well as create and control production schedules.

Keywords*—Fuzzy Reasoning, House of Risk, Supply Chain, Risk, Wooden toys industries.*

1. Introduction

All of activities occurr in the supply chain is potentially at risk. Some examples of supply chain risks are raw material shortages, supplier failures, rising raw material prices, engine breakdowns, uncertain demand, inaccurate forecasting, order changes, and transport failures. The potential incidents of these risks if they actually occured will be impact on the company's supply chain management performance [13]. The handling of the disruptive risks in the supply chain is called Supply Chain Risk Management (SCRM) [12]. SCRM is the identification and management of risks either in internal and external supply networks through a coordinated approach between supply chain members to reduce overall supply chain vulnerability [6].

The benefits of SCRM are to identify and assess interference and reduce the negative impact of supply chain performance. Ref. [8] stated that the concept framework of SCRM consists of 4 stages of identifying risks, conducting risk assessments, mitigating and monitoring. Various methods have been developed in the management of supply chain risks such as qualitative, quantitative-analytic, and quantitative-empirical methods. The most widely used method is quantitative-analytic method, then qualitative method, and the least used method is quantitative-empirical method and there are only about 40 articles that develop quantitative method Integrated [8]. The self-integrated quantitative method is a combination of two quantitative methods used simultaneously to solve problems in supply chain risk management. With the development and implementation of these SCRM methods at a strategic level will have a significant positive impact on its users [9].

Supply Chain Risk Management is a blend of the concept of Supply Chain Management with Risk Management. The risks to the supply chain can be defined as a place of events caused by an imbalance between demand and supply. Supply chain disruptions can lead to problems such as lead time, stock out, inability to meet customer demand, and increased costs [3][4]. The magnitude of risk can be measured by considering two fundamental parameters of risk, namely the possibility of risk and risk severity [4]. However, it must be realized also that the extent of certain risks is also highly dependent on many factors involved, such as human factors, workplace factors, material and equipment factors, etc. that are difficult to measure and handle in the traditional way [14]. Given these factors, the risk assessment should be well considered so that the results obtained from the assessment can be relied upon. Research using integrated risk management method has been done by many researchers. As the integrated Analytic Network Process (ANP) and Weighted Failure Mode Effects Analysis (WFMEA) methods are used to identify and analyze the highest risks in the cocoa supply chain by Aini [1]. Then the method of integrated Fuzzy reasoning and fuzzy analytical hierarchy process conducted by An [2]. Development of AHP fuzzy by ref. [5]. The simple but very useful use of House of Risk (HOR) by Pujawan [10][11]. In 2011 up to 2014 there was an

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increase of almost 50% of the number of scientific publications which put forward the SCRM theme. However, only less than 1% discussed SCRM in information technology, integrated methods, and collaborative management. The industries covered by the SCRM are automobiles, electronics, computers, aerospace equipment and supplies, daily necessities, oil, heavy industry, meat and plastic. While industries that have never been reviewed by the SCRM are industrial agricultural equipment, compressors, furniture, compressors, steel, and telecommunications [9].

2. Research Method

Fuzzy Reasoning House of Risk (FRHOR) is a hybrid method which combining House of risk and Fuzzy Reasoning risk assessment model. House of Risk Model is used to identify risk agent and focused in preventive actions [10][11]. This method begins by identifying risk agent and risk event by evaluating the severity level of each risk event, assessing occurence level of each risk agent, and the last is assessing the correlation between risk agent and risk event. Selecting the risk agents are doing by selecting the risk agent that has the highest ARPj value. ARPj calculated with equation 1.

$$ARP_j = O_j \sum_i S_i R_{ij} \quad \text{.......................................(1)}$$

Where:
O_j is occurrence score (1-10) of risk agent
S_i is severity score (1-10) of risk event
R_{ij} is correlations score between risk event and risk agent (0 = nothing correlations, 1 = low correlations, 3 = medium correlations, 9 = very high correlations)

After completing ARPj, Fuzzy Reasoning Risk Assessment Model based on fuzzy reasoning is proposed [10]. In this technique each expert used has a different value contribution different according to expertise and background of each expert. The fuzzy number approach used is Standardized Trapezoidal Fuzzy Number (STFN). The algorithm of the risk model consists of five phases: preliminary phase, measurement of FI phase, measurement of RL and RS phase, fuzzy inference phase and output modification phase.

Preliminary Phase

This stage is determining the contribution factor of each expert, determination of fuzzy membership functions, and the last is to make the hierarchy of factor index.

Measurement of FI phase

Step 1: Measure risk factors in the FI hierarchy
Each expert evaluates each sub factor use a linguistic variable made by reseacher using a questionaire.
Step 2: Compare risk factors pair-wise.
Each expert compare each factor in pairs according to the hierarchical structure of the factor index.

Step 3 : Convert preferences into the STFN.
Let U be the universe of discourse = [0,u]. A STFN can be defined as $A^* = (a^l, a^m, a^n, a^u)$, where $0 \leq a^l \leq a^m \leq a^n \leq a^u \leq u$, and its MF is

$$\mu_{A^*}(x) = \begin{cases} \frac{x-a^l}{a^m-a^l} \, for \, a^l \leq x \leq a^m \\ 1 \\ \frac{a^u-x}{a^u-a^n} \, for \, a^m \leq x \leq a^n \\ 0 \, for \, otherwise \end{cases} \quad \text{..................(2)}$$

Step 4: Aggregate individual STFN into group STFN.
To change individual STFN into group STFN, it can use the following equation 3:

$$S_i^* = S_{i1}^* \otimes c_1 \otimes S_{i2}^* \otimes c_2 \oplus \ldots \oplus S_{im}^* \otimes c_m \quad \text{..................(3)}$$

Where S_i^* is fuzzy aggregated score from F_i, while $S_{t1}^*, S_{t2}^*, \ldots\ldots S_{tn}^*$ is score from F_i, and $c_1, c_2, \ldots\ldots c_n$ is allocated from each expert . c_1 is derived from value of CF which is the allocation of each expert who perform the assessment. $E_1, E_2, \ldots\ldots E_n$ and $c_1+c_2+c_3+\ldots..c_n=1$.
While to change the score of the results compare between factors into group STFN, it can use equation 4.

$$a_{ij}^* = a_{ij1}^* \otimes c_1 \otimes a_{ij2}^* \otimes c_2 \oplus \ldots \oplus a_{ijm}^* \otimes c_m \quad \text{.........(4)}$$

Where a_{ij}^* is aggregated fuzzy scale from F_i compare, while $a_{ij1}^*, a_{ij2}^*, \ldots\ldots a_{ijn}^*$ is score correlation STFN scale from F_i comparasions and $c_1, c_2, \ldots\ldots, c_n$ is allocated from each expert. Note that aggregation should throw 0. If input is zero, then the input used is input provided for the same comparisons by another expert. It can calculate with equation 5.

$$a_{ij}^* = \frac{a_{ij1} \otimes c_1 \oplus a_{ij2} \otimes c_2 \oplus \ldots \oplus a_{ijm} \otimes c_m}{1 - \sum c_r} \quad \text{.........(5)}$$

Where c_r is expert CF expert giving the scales 0.
Step 5: Defuzzify the STFN scales.
Defuzzyify is change STFN scale into crisp score. Equations 6 is equations to use calculate it.

$$a_{ij} = \frac{a_{ij}^l + 2\left(a_{ij}^m + a_{ij}^n\right) + a_{ij}^m}{6} \quad \text{..............................(6)}$$

Step 6: Calculate the priority weights of risk factors.
Output from equation six becomes input of equations 7.

$$A = a_{ij} = \begin{matrix} F_1 \\ F_2 \\ F_3 \\ F_4 \end{matrix} \begin{bmatrix} F_1 & F_2 & \ldots & F_n \\ 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \ldots & a_{2n} \\ \vdots & \ldots & \ddots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}, i, j = 1,2,, n \ldots(7)$$

Where $a_{ii} = 1, a_{ji} = \frac{1}{a_{ij}}$

Next step to calculate priority weights of risk factors matrix A with use arithmetic averaging method, where equations 8 is:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \, i, j1,2, \ldots\ldots, n \ldots\ldots\ldots\ldots\ldots..(8)$$

where w_i is the section weight of Fi. Assume Fi has t upper sections at different level in the FI hierarchy. The final weight w_i' of Fi can be derived by,

$w_i' = w_i x \prod_{i=1}^{t} w_{section}^{(i)}$ ………...……….........(9)

Step 7: Calculate FI

When result score from priority weights of risk factors, then score Fi can be calculate equations 10.

$FI^* = \sum_{i=1}^{n} S_i^* w_i'$ i=1,2,……,n………………(10)

Where FI^* is result fuzzy from FI, represented by STFN, S_i^* is fuzzy aggregated score that can calculate by equation 3.

Measurement of RL and RS Phase

This stage begins with an assessment of each expert used and followed by converted into individual STFN and converted into group STFN with use equations :

$RL^* = RL_1^* \otimes c_1 \oplus RL_2^* \otimes c_2 \dots \oplus RL_m^* \otimes c_m$ ………..(11)

$RS^* = RS_1^* \otimes c_1 \oplus RS_2^* \otimes c_2 \dots \oplus RS_m^* \otimes c_m$………..(12)

Where RL* and RS* is result from fuzzy aggregated from RL and RS. RL_1^*, RL_2^*, ……, RL_m^* dan RS_1^*, RS_2^*, ……….,RS_m^* is evaluation from level occurrence and level severity from risk agent which are represented by expert.

Fuzzy Inference system generate a mapping between parameter input FI*, RL*, RS* and *output* RM*. Three parts in the premise connected to "and" and firing strength μ_{R^k} from fuzzy rule can optimization use fuzzy intersection (minimum) operation is given by

$\mu_R^k(x,y) = \mu_{FI^*}^k(x_1) \wedge \mu_{RL^*}^k(x_2) \wedge \mu_{RS^*}^k(x_3) \wedge \mu_{RM^*}^k(y)$ .....(14)

K = 1, 2, ….. , K.

Where $x_1 \in X_1$, $x_2 \in X_2$, $x_3 \in X_3$, $\chi \in X_1 \times X_2 \times X_3$ and $y \in U$. X_1, X_2, X_3 and U denote the universe of FI*, RL*, RS* and RM*, respectively. Next, calculate RM with equation 15 and 16.

$\mu R(\chi, y) = \vee_{K=1}^{K} R^k(\chi, y)$………………...(15)

$RM^* = RP^* o R(\chi, y)$……………………...(16)

Defuzzyfication

This step is to convert output of the RM fuzzy in the form of numerical value of the Risk Magnitude. This result can be calculated by using equation 17.

$RM = (\sum_{i=1}^{q} Yi\mu_{RM^*}(y_i))/(\sum_{i=1}^{q} \mu_{RM^*}(y_i))$…………...(17)

A. Whereas, yi denotes the centre of the ith fuzzy term set of RM*, and μ_{RM^*} (yi) denotes the MF of the ith fuzzy term set of RM*.

Output Modification Phase

The output modification is necessary in some situations for securing a reliable decisions, for instance, the circumstances of risks have been changed, the impact of some risk factors have not been changed, the impact of some risk factors have not been adequately measured.

3. Result and Discussion

This stage is identifying the most potential risk agent in wooden toys industries supply chain activity. Based on interviews and observations, there is 25 risk events (Table 1) and 28 risk agents (Table 2). Assess the impact (severity) of such risk event (if happened) and assess likelihood of occurrence of each risk agent. The step is to determine correlations between risk event and risk agent, and the last step is to calculate of Aggregate Risk Potential (ARP). The results ARPj change into presentation represented Pareto chart diagram in Figure 1.

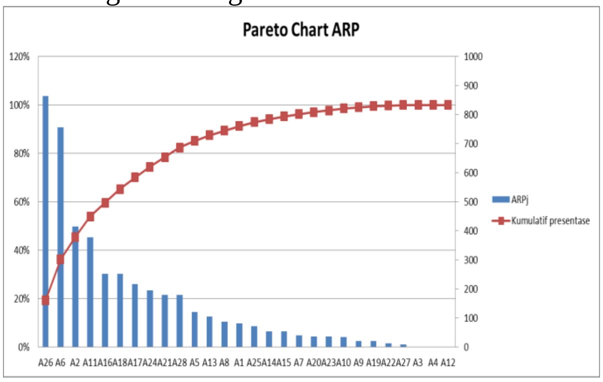

Figure 1. Result Calculate Agregat Risk Potential

Figure 1 shows the result that risk agent has highest percentage of ARPj is A26 wich is stock out product and A6 is human error. Percentage ARPj for risk agents stock out product is 19% and percentage ARPj for risk agent is 17%.

Table1. Result Identification Risk Event

Code	Risk Event
E1	Material does not come according to schedule
E2	Sudden change productions planning
E3	Production process is not in accordance with the schedule made
E4	Suppliers unable to fulfill material requirement
E5	Error quality checking procedure when material came
E6	Incompability between the amount of material ordered and reuired
E7	Delevery material from suppliers is comelate
E8	Production process run late is not in accordance with the target time
E9	Stok out material when productions process
E10	Stacking elements on one workstations
E11	Erorr grouping WIP (Work In Process)
E12	Quality product is bad
E13	Error quantity product in productions
E14	Quantity product produced is not same as expected
E15	Error in moving product on production plant
E16	Delay delevery product base on expired to showroom
E17	Delay delevery product to showroom
E18	Delay delevery product to end customer (online shop)
E19	Delay delevery product base on expired to end customer
E20	Delay delevery product to *end customer*
E21	Product is damaged when it reaches the end customer
E22	Incompability between the note and the product sent in either type or quantity
E23	Error of the logistic provider in delivering product
E24	Return of defective material in reject
E25	Delays in handling the products returned by the customers

Table 2. Result Identification Risk Agent

Code	Risk Agent
A1	Intern problem in supplier
A2	Sudden customer requirements
A3	Material one of product stick out
A4	Damage to one of the machine
A5	Delays in the issuance of purchase orders
A6	*Human Error*
A7	Not all opertors understand about material checking SOP
A8	Damage to means of transportation used
A9	Trapped congestion when delivering products to the showroom or customer
A10	Delay delivered material by *supplier*
A11	Quantity of material that come does not match the needs of productions
A12	Damage to one of machine
A13	*Stock Out* material in werehouse
A14	Error in planning of material needs
A15	Damage to machine on one workstation
A16	Operator skills are still lacking
A17	Lay out the factory is not tidy
A18	Quality material is bad
A19	Internal communication system is not good
A20	Some of the products have low quality
A21	Production process is delayed
A22	Type of product returned is different from type of product being produced
A23	Returns are made past the supplier's time limit
A24	Showroom is late publish storeroom requisition
A25	Delay deliver from showroom to logistic provider
A26	Stock out product in Showroom
A27	Error while structuring product on the mean of transportation
A28	Product treatment error performed logistic provider

Base on calculate use equation 2 to equation 10, we get the weight of index factor that influence the risk agent from stock out product with value,
FI* = (1.2286, 3.3221, 3.3221, 7.9818).
While, result from the weight of the index factor that affect the human error risk agent, ie
FI* = (1.12438, 2.19935, 2.1994, 4.168).

Measurement of RL and RS Phase

Base on calculate use equation 11 and equation 12, we get aggregated STFN from measurement RL and RS to risk agent stock out product is,
RL* = (3.7500, 6.2500, 6.2500, 8.7500)
RS* = (1.2500, 2.5000, 2.5000, 5.0000)
While, result aggregated STFN from measurement RL and RS to risk agent human error is,
RL* = (3.7500, 6.2500, 6.2500, 8.7500)
RS* = (3.1250, 5.6250, 5.6250, 8.125)

Fuzzy Inference Phase

In this phase begins by convert STFN number into fuzzy sets. Result of conversion into from of fuzzy sets of value owned by risk agent stock out product, namely:
FI* = {(High impact, 0.50856), (certain impact, 0.67116), (low impact, 0.32884), (critical impact, 0.8073), (ignorance impact, 0.1927)}.
RL* = {(low, 0.5), (medium, 0.5), (high, 0.5), (very high, 0.5)}
RS* = {(very low, 0.5), (low, 1), (medium 1), (high, 0)}
While, result of convertion for risk agent human error, is:
FI* = {(high, 0.55025), (certain impact, 0.44975), (low impact, 0.6672)}
RS* = {(low, 0.75), (medium, 0.75), (high, 0.75), (very high, 0.25)}
RL* = {(low, 0.5), (medium, 0.5), (high, 0.5), (very high, 0.5)}

After conversion, the next step is fuzzy inference system. In this system correlation between parameter input FI*, RL*, RS* and result RM* rare presented at if-then rules functions in equations 13. Base on expert judgment for risk agent stock out of product with input mapping FI* x RL* x RS* obtained 80 rule. The output of 80 rules in the case of stock out of warehouse product is shown in Table 5. In human error case, we get result combination FI* x RL* x RS* is 48 rule. Result output from 48 rule in Table 6. Base on equation 15 and 16 for risk agent stock out product get result, that is,
RM* = {(0.5, µSK(RM*)), (0.5, µMi(RM*)), (0.5, µMa(RM*)),(0.5, µKr(RM*))}

Table 5.Result Output Rule for Risk Agent Stock Out Product

Faktor indeks	Dampak Risiko *(Risk Severity)*	Peluang Risiko (*Risk Likelihood*)			
		R (0.5)	C (0.5)	T (0.5)	ST (0.5)
DTA (0.1927)	SR (0.5)	SK (0.1927)	SK (0.1927)	Mi (0.1927)	Mi (0.1927)
	R (1)	SK (0.1927)	SK (0.1927)	Mi (0.1927)	Mi (0.1927)
	C (1)	SK (0.1927)	Mi (0.1927)	Mi (0.1927)	Ma (0.1927)
	T (0)	Mi (0)	Ma (0)	Kr (0)	Kr (0)
DTK (0.8073)	SR (0.5)	SK (0.5)	SK (0.5)	Mi (0.5)	Mi (0.5)
	R (1)	SK (0.5)	SK (0.5)	Mi (0.5)	Mi (0.5)
	C (1)	SK (0.5)	Mi (0.5)	Ma (0.5)	Ma (0.5)
	T (0)	Mi (0)	Ma (0)	Kr (0)	Kr (0)
DK (0.32884)	SR (0.5)	SK (0.32884)	SK (0.32884)	Mi (0.32884)	Mi (0.32884)
	R (1)	SK (0.32884)	Mi (0.32884)	Mi (0.32884)	Ma (0.32884)
	C (1)	Mi (0.32884)	Ma (0.32884)	Ma (0.32884)	Kr (0.32884)
	T (0)	Mi (0)	Ma (0)	Kr (0)	Kr (0)

As for the result of equation RM* for risk agent human error obtained result, that is:

RM* = {(0.5, µSK(RM*)), (0.5, µMi(RM*)), (0.5, µMa(RM*)), (0.5, µKr(RM*))}

Next step is defuzzification use equation 17. In stock risk agents out products in the warehouse obtained RM value of 5.5, while human error agent error generated RM value of 5.5.

Based on the result of RM value, then convert into the form of fuzzy sets by taking intersection between lines on the graph Figure 3. Because the hail of the RM value of the risk agent stock out products and human risk agent's value in the form of fuzzy sets is the stock out the amount of impacts Product risk agents and human error are minor by 25% and major 75%.

Output Modification Phase

Based on the results of fuzzy inference obtained minor value is 25% and major value is 75%. Minor means that impact of risk agent can still be tolerated but must be controlled, while the major means impact of risk agent should be reduced using practical measures. Based on the value obtained it is seen that the position of the stock risk agent out products and human error is more dominant on the major, so it can be drawn conclusion that both the impact caused from the stock risk agent products and human error risk agents must be reduced so that the impact does not hamper Supply chain performance. Alternative mitigation strategies that can be used to reduce the impact of stock risk agents out of warehoused products are flexible supply base, create safety stock, internal coordination, and create and control production schedule. Meanwhile, alternative strategies used to reduce the impact of human error risk agents are internal coordination, create and control production schedules, conduct employee training, supervise, reward and punishment, and provide a comfortable and clean environment for workers

Table 6. Result Output Rule for Risk Agent Human Error

Faktor indeks (FI)	Dampak Risiko (*Risk Severity*)	Peluang Risiko (*Risk Likelihood*)			
		R (0.5)	C (0.5)	T (0.5)	ST (0.5)
DK (0.6672)	R (0.75)	SK (0.5)	Mi (0.5)	Mi (0.5)	Ma (0.5)
	C (0.75)	Mi (0.5)	Ma (0.5)	Ma (0.5)	Kr (0.5)
	T (0.75)	Mi (0.5)	Ma (0.5)	Kr (0.5)	Kr (0.5)
	ST (0.25)	Mi (0.25)	Ma (0.25)	Kr (0.25)	Kr (0.25)

4. Conclusion

Based on result and analysis conducted in the previous stage, it can be concluded by, based on Fuzzy House of Risk, result show that risk agent stock out product (19%) is more likely than human error (17%). While, the risk magnitude of both the stock risk agent of product and risk agent human error if it occurs is the same (major 75% and minor 25%), ie inhibiting supply chain performance. Alternative mitigation strategies that can be used to reduce the impact of risk stock out agents in the warehouse are flexible supply base, creating safety stock, improving internal coordination.

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