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Prioritization of Risks in Bicycle Supply Chain using Fuzzy Analytic Hierarchy Process

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***Abstract*— Recent supply chain management optimization practices, while reducing costs and leaning inventory levels, have left companies with unprecedented levels of risk exposure and very little buffer inventory with which to recover. Many companies have recognized this and are now undertaking supply chain risk management programs. This work deals with the application of Multi Criteria Decision Making (MCDM) techniques such as Fuzzy Analytic Hierarchy Process (FAHP) for prioritization of eight supply chain risks with corresponding sub-risks identified through literature and the expert opinion for a bicycle manufacturing company.**

Keywords*— *Supply chain Management; Risk Management; FAHP; Prioritization

I. INTRODUCTION

A supply chain is a network of facilities and distribution options that performs the functions of procurement of materials, transformation of these materials into intermediate and finished products, and the distribution of these finished products to customers. While the term "Supply Chain Management" is widely used, there is not general agreement as to the definition and scope of the SCM concept. In fact, during the last several decades, the term itself has evolved from "Distribution" to "Logistics" to "Supply Chain Management." The objective of the supply chain is to support the flow of goods and materials from the original supplier through multiple production and logistics operations to the ultimate consumer. Risk means Exposure to the chance of injury or loss, Hazard or dangerous chance, Chance of loss, Degree of probability of such a loss. The objective of this work is to identify various risks in the bicycle supply chain and rank those using Multi Criteria Decision Making (MCDM) technique called Fuzzy Analytic Hierarchy Process (FAHP)

II. LITERATURE REVIEW

This section deals briefly the review of literature related to risks in supply chain and Multi criteria Decision Making (MCDM) techniques which support the decision-makers (DMs) in evaluating a set of alternatives. Depending upon the situations, criteria have varying importance and there is a need to weigh them.

Wu et al (2005) performed research in reinforce inbound supply chain risk management by proposing an integrated methodology to classify, manage and assess inbound supply risks. The contributions of this work are four-fold: (1) inbound supply risk factors are identified through both an extensive academic literature review on supply risk literature review as well as a series of industry interviews; (2) from these factors, a hierarchical risk factor classification structure is created; (3) an analytical hierarchy processing (AHP) method with enhanced consistency to rank risk factor for suppliers is created; and (4) a prototype computer implementation system is developed and tested on an industry example.

Different types of SC vulnerability management methodologies have been proposed for managing SC risk, most offer only point-based solutions that deal with a limited set of risks. Moeinzadeh et al (2010) reinforced SC risk management by proposing an integrated approach. SC risks are identified and a risk index classification structure is created. Then they developed a SC risk assessment approach based on the Analytic Network Process (ANP) and the VIKOR methods under the fuzzy environment where the vagueness and subjectivity are handled with linguistic terms parameterized by triangular fuzzy numbers. By using FANP, risks weights are calculated and then inserted to the FVIKOR to rank the SC members and find the most risky partner.

Singhal et al (2011) provided the insights on the linkages of risks and their key drivers by devising a combined regression and neural network model by unifying their significant aspects. The major risk issues are identified at operational level in the form of supply disruptions, demand volatility and infrastructural obsolescence. For an uninterrupted functioning of the firm, identification of key risks and their potential drivers is an extremely important managerial task.

Krisnawati et al., (2018) analyzed the pattern of five supply chain flow models and its 21 risks, in which 11 of them were mitigated. They also implemented ISO 31000:2009 to mitigate the risks. Jiang et al., (2017) use Matlab to simulate the transmission model in which relation between supply chain enterprises was determined. It also suggested that credit risk of core enterprise need to be paid attention. Tunc et al., (2017) revealed the key risk management strategies responsible for increased company sales. They also provided a comprehensive understanding of supply chain risk management using quantifying data mining approach. Kraude et al., (2018) explored the relationship between environmental and location or cultural factors in three countries by conducting a survey. In this process, they showed that Japan has a higher level of perceived SCR and lower application of risk mitigation strategies than two western culture countries, the USA and Australia. Kotula et al., (2018) found that risk management has not been adopted fully across industries and countries from a strategic sourcing perspective in Germany and the United Kingdom. They also present several significant insights for managing risks in strategic sourcing.

Yiyi Fan and Mark Stevenson (2018) done a detailed review of 354 articles on supply chain risk management, in which they emphasized organizational responses to supply chain risks and made only limited use of theory. Baryannis et al., (2018) conducted an investigation on the various definitions and classifications of supply chain risk and related notions such as uncertainty and applied Artificial Intelligence (AI) techniques in SCRM. This study gives directions for future research at the confluence of SCRM and AI. Hariharan and Rajmohan (2015) applied MCDM techniques such as AHP, FAHP and TOPSIS in prioritizing the supply chain risks in a bicycle manufacturing company. From there study they found that supply risk has a major impact in the supply chain. Joshua Kiptum and Barack Okello (2018) examine the influence of purchasing risk management on supply chain performance of manufacturing firms in Nakuru County, Kenya. Supply assurance from the suppliers and improper supplier selection were the key terms to be addressed to ensure improvement in supply chain performance. Jeroen et al., (2018) focused on the relationship between a service provider and a customer that acted on behalf of other users in the defense sector. The service provider's performance attributability appeared to have a strong impact on its willingness to take PBC-induced risks. The service provider's willingness to accept PBC-induced risks was also affected by its ability to make accurate forecasts, the applied growth path and the length of the contract.

Azadeh et al (2010) presented a robust decision-making methodology based on FAHP for evaluating and selecting the appropriate simulation software package. The robust decision method aggregates the experts' judgments for the criteria weights and the suitability of simulation software alternatives. The FAHP is used to prioritize and evaluate existing alternatives based on the proposed criteria for choosing the proper simulation software.

III. METHODOLOGY

This section explains the methodology followed in this work to identify the critical risks in the bicycle supply chain. In MCDM, a problem is affected by several conflicting factors in selection, for which a manager must analyze the tradeoff among the several criteria. The Fuzzy Analytic Hierarchy Process (FAHP) is a structured technique for dealing with complex decisions. AHP helps decision makers to find one that best suits their goal and their understanding of the problem.

The fuzzy AHP technique can be viewed as an advanced analytical method developed from the traditional AHP. Despite the convenience of AHP in handling both quantitative and qualitative criteria of multi-criteria decision making problems based on decision maker's judgments, fuzziness and vagueness existing in many decision-making problems may contribute to the imprecise judgments of decision makers in conventional AHP approaches. So, many researchers who have studied the fuzzy AHP which is the extension of Saaty's theory, have provided evidence that fuzzy AHP shows relatively more sufficient description of these kind of decision making processes compared to the traditional AHP methods.

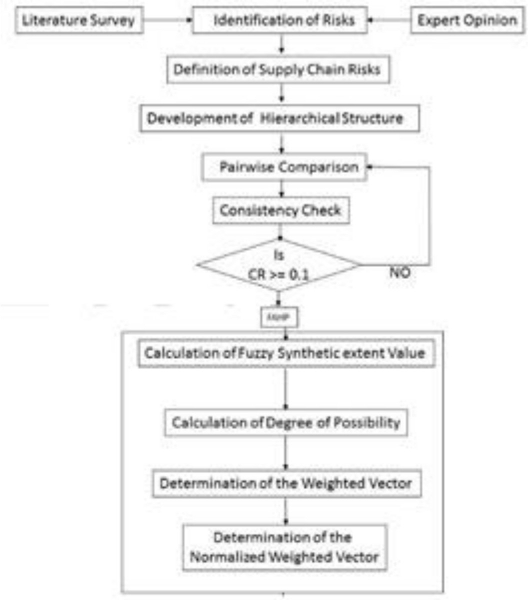

Fig. 1. Schematic Diagram for Prioritizing the Supply Chain Risk

IV. CASE STUDY

The developed model is applied to a bicycle manufacturing company located in southern part of India. A supply chain of particular brand is selected for implementation of the methodology shows in fig 1. In this case, eight risks in the supply chain are considered and prioritized with corresponding sub risks. This section provides the steps needed to calculate the priority value to rank the supply chain risk using FAHP for the case study considered. Eight risks namely Supplier, Storage, Process, Demand, Information, Transportation, Finance and Environment were identified as the relevant risks for this case through literature and expert opinion. The definition of each risk is given below.

1. Supply Risk (SU) - All issues with the movement of materials into an organization, including sources, supplymarket conditions, constraints, limited availability, supplier reliability, lead times, material costs, delays, etc.,

2. Storage Risk (ST) - Lack of care in maintaining quality, space lacking for storage.

3. Process Risk (PR) - Risks from product features, product mix, range, volumes, materials used and standardization.

Demand Risk (DE) - All aspects of customer demand, such as level of demand, variability, alternative products, competition and patterns of change.

5. Information Risk (IN) - Includes the availability of data, data transfer, accuracy, reliability, security of systems.

6. Transportation Risk (TR) - Movements of materials, including risks to the infrastructure, vehicles, facilities and loads.

7. Finance Risk (FI) - all money transactions, including payments, prices, costs, sources of funds, profit and general financial performance.

8. Environment Risk (EN) - Risks that are external to the supply chain.

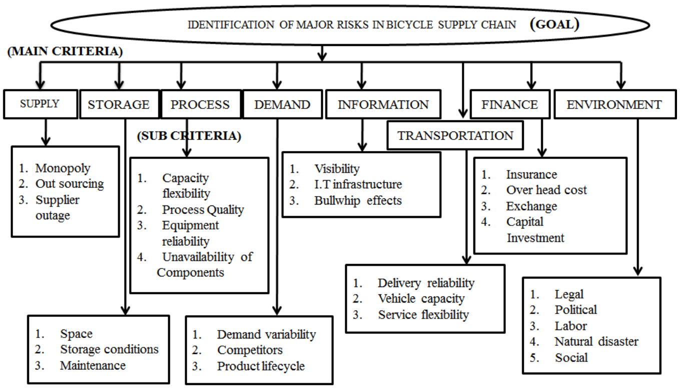

Fig. 2. Hierarchy Structure for Prioritizing Supply Chain Risks

Fig 2 shows the Hierarchical model of AHP where various risks in supply chain were categorized to the eight main risk factors.

To apply the process depending on this hierarchy, according to the method of Chang's (1992) extent analysis, each criterion is taken and extent analysis for each criterion, g_i is performed on, respectively. Therefore, m extent analysis values for each criterion can be obtained by using following notation.

$M_{gi}1$, $M_{gi}2$, $M_{gi}3$, $M_{gi}4$, ………….. $M_{gi}m$,where gi is the goal set (i = 1, 2, 3, 4, 5, ...n) and all the jgM (j = 1, 2, 3, 4, 5,........, m) are Triangular Fuzzy Numbers (TFNs). The steps of Chang's analysis can be given as in the following:

Step 1: Fuzzy synthetic extent value (Si)

The fuzzy synthetic extent value (Si) with respect to the i th criterion is defined as equation (1).

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \qquad (1)$$

To obtain Equation $\sum_{j=1}^{m} M_{gi}^{j}$ (2)

Perform the "fuzzy addition operation" of m extent analysis values for a particular matrix given in equation (3) below, at the end step of calculation, new (l, m, u) set is obtained and used for the next:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \qquad (3)$$

Where l is the lower limit value, m is the most promising value and u is the upper limit value. Table 1 shows the pairwise matrix for main criteria. To obtain equation (4); perform the "fuzzy addition operation" of M_{gi}^{j} (j = 1, 2, 3, 4, 5, ..., m) values give as equation (5): and then compute the inverse of the vector in the equation (5) equation (6) is then obtained such that

$$\left[\sum_{i=`}^{n}\sum_{j=1}^{,m} M_{gi}^{j}\right]^{-1} \qquad (4)$$

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{i=1}^{m} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i\right) \qquad (5)$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \qquad (6)$$

S1 = Σ SUij / SUM
=((1+1.5+0.65+1.5+0.65+1.5+1.5+1.5+3.5),
(1+2+1+2+1+2+2+4),
(1+2.5+1.5+2.5+1.5+2.5+2.5+4.5))
/ (54.33, 69.61, 93. 99)
= (11.83, 14, 18.5)/ (54.33, 69.61, 93.99)
= (0.13, 0.2, 0.34)

Similarly for S2,….., S8. Table 2 shows the fuzzy synthetic extent value for the main criteria.

Table 2 Fuzzy Synthetic extent value.

	l	m	u
S1	0.13	0.2	0.34
S2	0.05	0.1	0.18
S3	0.07	0.13	0.22
S4	0.08	0.14	0.24
S5	0.05	0.1	0.18
S6	0.07	0.12	0.2
S7	0.06	0.11	0.19
S8	0.06	0.1	0.19

Step 2: The degree of possibility

The degree of possibility of $M_2 = (l_2, m_2, u_2) \ge M_1 = (l_1, m_1, u_1)$ is defined as equation (7)

$$V(M_2 \ge M_1) = \sup_{y \ge x}\left[\min(\mu_{M_1}(x), \mu_{M_2}(y))\right] \qquad (7)$$

and x and y are the values on the axis of membership function of each criterion. This expression can be equivalently written as given in equation (8) below:

$$V(M_2 \ge M_1) = \begin{cases} 1, if\,(m_2 \ge m_1) \\ 0, if\,(l_1 \ge u_2) \\ \dfrac{l_1 - u_2}{(m_2 - u_2)(m_1 - l_1)}, otherwise \end{cases}$$

(8)

Where d is the highest intersection point μM1 and μM2.

Table 1 Pairwise Comparison matrix for FAHP

Criteria	SU	ST	PR	DE	IN	TR	FI	EN
SU	1,1,1	1.5,2,2.5	0.67,1,1.5	1.5,2,2.5	0.67,1,1.5	1.5,2,2.5	1.5,2,2.5	3.5,4,4.5
ST	0.4,0.5,0.67	1,1,1	0.67,1,1.5	.29,.33,.43	0.67,1,1.5	0.67,1,1.5	0.67,1,1.5	0.67,1,1.5
PR	0.67,1,1.5	0.67,1,1.5	1,1,1	1,1,1	1.5,2,2.5	0.67,1,1.5	0.67,1,1.5	0.67,1,1.5
DE	0.33	2.5,3,3.5	1,1,1	1,1,1	0.67,1,1.5	1,1,1	0.67,1,1.5	0.67,1,1.5
IN	0.67,1,1.5	0.67,1,1.5	0.25	0.67,1,1.5	1,1,1	0.4,0.5,0.67	0.67,1,1.5	0.67,1,1.5
TR	0.4,0.5,0.67	0.67,1,1.5	0.67,1,1.5	1,1,1	1.5,2,2.5	1,1,1	1,1,1	0.67,1,1.5
FI	0.4,0.5,0.67	0.67,1,1.5	0.67,1,1.5	0.67,1,1.5	0.67,1,1.5	1,1,1	1,1,1	0.67,1,1.5
EN	0.22,0.25,0.29	0.67,1,1.5	0.67,1,1.5	0.67,1,1.5	0.67,1,1.5	0.67,1,1.5	0.67,1,1.5	1,1,1
SUM= (54.33, 69.61, 93.99)								

To compare M1 and M2; we need both the values of $V(M2\geq M1)$ and $V(M1\geq M2)$;

Check the condition by comparing 2 values S1 and S2, and for all combination using equation (7) and (8).

$V(S1\geq S2)=1$, $V(S1\geq S3)=1$, $V(S1\geq S4)=1$, $V(S1\geq S5)=1$, $V(S1\geq S6)=1$, $V(S1\geq S7)=1$, $V(S1\geq S8)=1$, $V(S2\geq S1)=0.33$, $V(S2\geq S3)=0.77$, $V(S2\geq S4)=0.71$, $V(S2\geq S5)=0.98$, $V(S2\geq S6)=0.77$, $V(S2\geq S7)=0.92$, $V(S2\geq S8)=0.95$, $V(S3\geq S1)=0.57$, $V(S3\geq S2)=1$, $V(S3\geq S4)=0.95$, $V(S3\geq S5)=1$, $V(S3\geq S6)=1$, $V(S3\geq S7)=1$, $V(S3\geq S8)=1$, $V(S4\geq S1)=0.64$, $V(S4\geq S2)=1$, $V(S4\geq S3)=1$, $V(S4\geq S5)=1$, $V(S4\geq S6)=1$, $V(S4\geq S7)=1$, $V(S4\geq S8)=1$, $V(S5\geq S1)=0.35$, $V(S5\geq S2)=1$, $V(S5\geq S3)=0.79$, $V(S5\geq S4)=0.73$, $V(S5\geq S6)=0.83$, $V(S5\geq S7)=0.94$, $V(S5\geq S8)=0.97$,

$V(S6\geq S1)=0.47$, $V(S6\geq S2)=1$, $V(S6\geq S3)=0.95$, $V(S6\geq S4)=0.89$, $V(S6\geq S5)=1$, $V(S6\geq S7)=1$, $V(S6\geq S8)=1$, $V(S7\geq S1)=0.4$, $V(S7\geq S2)=1$, $V(S7\geq S3)=0.84$, $V(S7\geq S4)=0.78$, $V(S7\geq S5)=1$, $V(S7\geq S6)=0.89$, $V(S7\geq S8)=1$, $V(S8\geq S1)=0.4$, $V(S8\geq S2)=1$, $V(S8\geq S3)=0.82$, $V(S8\geq S4)=0.77$, $V(S8\geq S5)=1$, $V(S8\geq S6)=0.87$, $V(S8\geq S7)=0.97$.

Step 3: The degree possibility for a convex fuzzy number

The degree possibility for a convex fuzzy number to be greater than k convex fuzzy number Mi(i= 1,2,3,4, ……….,k) can be defined by

$$V(M\geq M1,M2,M3,\ldots,Mk)=\min V(M\geq Mi), i=1,2,3,\ldots,k.$$

Assume that equation (9) is $d'(Ai) = \min V(Si \geq Sk)$ (9)

For k=1,2,3,……., n;k≠i. Then the weight vector is given by equation (10);

$$W' = (d'(A1),d'(A2),\ldots\ldots, d'(An))^T \quad (10)$$

Where Ai(i=1,2,3,……..,n) are n elements.

Calculate the minimum of (S1 with Si) using equation (9), Min $V(S1>=Si)=1$

Similarly for S2,…., S8.

Min $V(S2\geq Si)=0.33$

Min $V(S3\geq Si)=0.57$

Min $V(S4\geq Si)=0.64$Min $V(S5\geq Si)=0.35$

Min $V(S6\geq Si)=0.47$

Min $V(S7\geq Si)=0.4$

Min $V(S8\geq Si)=0.4$

$W' = [1, 0.33, 0.57, 0.64, 0.35, 0.47, 0.4, 0.4]$

Step 4: Normalization

Via normalization, the normalized weight vector are given in equation (11);

$$W = (d(A1),d(A2),\ldots\ldots, d(An))^T \quad (11)$$

Where W is non fuzzy nujmbers.

W (Normalized) = [0.24,0.08,0.14,0.15,0.08,0.11,0.1,0.1]

Weights of Main Criteria:

MAIN CRITERIA	LOCAL WEIGHT
SUPPLIER	0.24
PROCESS	0.14
TRANSPORTATION	0.11
DEMAND	0.15
FINANCE	0.1
ENVIRONMENT	0.1
INFORMATION	0.11
STORAGE	0.08

Similarly by following the same procedure as main risk, weights of sub criteria also be calculated. By multiplying the local weights of each sub risks with corresponding main risks, the global weight of each risk will be obtained as shown below.

Weights of Sub Criteria :

SUB CRITERIA	G.WEIGHT
Monopoly	0.096
Equipment reliability	0.0504
Delivery reliability	0.0858
Demand variability	0.39
Process quality	0.0504
Capacity flexibility	0.0392
Exchange	0.003
Out sourcing	0.0672
Overhead cost	0.043
Service flexibility	0.0242
Legal	0.022
Bullwhip effects	0.0552
Natural disaster	0.02
Insurance	0.035
Storage conditions	0.0496
Product lifecycle	0.048
Visibility	0
Maintenance	0.0008
Political	0.02
Social	0.02
Supplier outage	0.0768
Competitors	0.0165
Vehicle capacity	0

Unavailability of components	0
IT infrastructure	0.0248
Labor	0.018
Capital investment	0.02
Space	0.0296

Supply risk is identified as the most primary risk followed by process risk and the storage risk is ranked as the least important risk among the eight risk considered in this study. As for as the sub risks, Demand variability is identified as the most primary risk followed by Monopoly risk also Vehicle capacity, Unavailability of components and Visibility risks are ranked as the least important risk

V. CONCLUSION AND FUTURE WORK

In current dynamic environment risk management became an extremely important activity in supply chain management. In this work, MCDM techniques FAHP was adopted to rank the critical supply chain risk for an bicycle manufacturing company. Eight important supply chain risks were identified as significant risk for the case considered. Supplier risk found to be the most important one and storage risk given the last priority. In future, for the same case other MCDM techniques like TOPSIS, DEMATEL, Fuzzy TOPSIS can be applied to guide decision makers.

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