Supply Chain Risk Management: Risk Assessment in Engineering and Manufacturing Industries

Hossein Rikhtehgar Berenji and R.N. Anantharaman

Abstract—**In recent years, supply changes have been becoming more complicated and sophisticated widespread. Supply chain management has faced much uncertainty (due to lack of trust to chain rings), resulting in some risks. This study is expected to identify and assessing the risk in supply chain using Fuzzy Analytic Network Process (for allocating weights to risk factors) and Fuzzy TOPSIS (for ranking the supply chain members). And finally do case study and check the model.**

Indexed Terms—**Supply chain risk management, fuzzy supply chain risk assessment, MAPNA Boiler Company, Fuzzy Analytic Network Process (FANP) and Fuzzy TOPSSIS**

I. Introduction

The aim of organizations and firms in the manufacturing era is in the direction of mass production with high circulation. In the next decades along with increased competitions, organisations will attempt to produce high quality products with lesser cost and in doing so, hope to achieve more competitive advantage. Therefore, activities such as providing materials, production planning, warehousing, inventory control, distribution, delivery and customer service, which previously were performed at the company level, have moved to supply chain level. In recent years, supply changes have been becoming more complicated and widespread. This supply chain management has faced much uncertainty (due to lack of trust to supply chain rings), resulting in some risks. Finally, achieving confident and successful management is not possible without supply chain management risk and trust among the members.

Christopher [1] generally defined supply chain management as managing up- and downstream relations with suppliers and customers so as to deliver maximum value to customers and to achieve least cost for supply chain. It seems that there is a consensus about this conclusion that in its simplest form, supply chain has three components: the company, supplier and customer [2]. These components are directly engaged in up- and downstream flows of products, services, financial resources and information. The key property is coordinating activities between independent organizations and Consistent with the understanding of risk, the key property of supply chain risk is that the risk extends beyond boundaries of company and highly increased transactions can be a source of supply chain risks [3]. Current business trends that may increase vulnerabilities to risk are the followings [4]:

1) Reduction of precautionary savings (Buffer) and delivery time;
2) Increased strategic outsourcing by companies;
3) Fast demand in high volume at the beginning of products life cycle;
4) Emerging information technology that has made possible the controlling and organising of widespread supply chains and etc.

For identifying, categorizing and assessing the risks in supply chain we need to use good and practical methods. In multi-criteria decision-making, people mentally consider different criteria in their decisions and these criteria would cause the decision to be less timely and less accurate. It also depends greatly on the person who makes the decision. To solve this problem or to reduce its lateral effects, some methods for decision making with multi-criteria are designed with each one of them following special rules and principles. Researchers have been focused on Multi Criteria Decision making Model (MCDM) in recent decades in order to use for complicated decision-makings in which multi criteria are used instead of one optimality measurement criterion in classic models of optimization. Decision makers often express their comments and views uncertainly. To resolve this problem, the fuzzy approach should be used [5]. In this research a Fuzzy Multi Criteria Decision Making Model (FMCDM) is developed to evaluate the risk in supply chain.

The objectives of this research are: 1) to identify supply chain risks using related literatures 2) to evaluate and index identified risks in the supply chain using Fuzzy Analytic Process (FANP). 3) implementing Fuzzy Technique for Order-Preference by Similarity to Ideal Solution (FTOPSIS) to rank supply chain members. 4) establishing some new methods and suggestions for supply chain risk assessment and management.

II. Supply Chain Management

During World War II, supply chain was a set of linear and discrete processes that connects manufacturers, warehouses, wholesalers, retailers, and customers in the form of paper/human chain [6].

At the beginning of 1960s and 1970, the firms see themselves as close functions that their common goal was serving to customers. Usually, this internal integration is called logistics management or materials management [7]. The term "supply chain management" first appeared in early 1980s when the authors used this word to describe and re-name a combination of established business activities such as logistics (transportation, warehousing and integrated distribution) and managing operations based on production (including components of logistics, ordering and inventory

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H. R. Berenji is with the Sharif University of Technology, Tehran, Iran and Multimedia University, Cyberjaya Campus, Malaysia (e-mail: h.rikhtehgar@gmail.com).

R. N. Anantharaman is with Business school, Multimedia University, Melaka Campus, Malaysia.

management, control and production planning, and customer service).

Despite novelty of this topic, Cooper et al. (1977) noted that large number of assumptions, such as information sharing and integration of all organizational interaction systems, have also existed in previous decades [8]. Today, competition is not among single companies and instead it is highly appeared among supply chains. Proper management of supply chain is related to an ability that allows companies to gain competitive advantage in the market [9].

Supply chain management considers supply chain and organizations within it as an entity. Supply chain management approach to understand and manage various activities within supply chain is a systematic approach. This systematic approach provides a framework to supply conflicting requirements of activities in the best possible manner.

III. Supply Chain Risk Management

In recent years, the term “risk” has been remarked in the researches about supply chain management. It must be noted that 100% security or 0% probability for supply chain risk is not possible in the real world. It is intended to determine a “controllable” risk/security level. The most important goal of supply chain risk management is to ensure that supply chains continue to work as planned, with smooth and uninterrupted flows of materials from initial suppliers through to final customers. It means decreasing the vulnerability of a supply chain, increasing its ability to withstand unexpected issues, improving sustainability or increasing resilience [4].

In UK, bankruptcy of a car chassis manufacturer called UPF Thompson at the end of 2001 imposed had sudden and irreparable effects on its main customer (i.e. Land Rover plant) and so the production process of them was stopped [10]. Recently ten-day holiday in 29 ports of US caused one million dollars losses per day for USA economy. These examples clearly show that affecting disruption on a company anywhere in the supply chain can make a direct effect on the company ability to continuing activities, providing goods for market, and/or supplying vital services for customers [3].

Considering above mentioned reasons, it can be stated that presently main challenge in the supply chain includes managing existing risks to achieve correct balance between product accessibility, cost, and capital management in modern business conditions and global complicated supply chains and so it is one of the successful management requirements in this area.

Chopra and Sodhi [11] introduced nine types of supply chain risk with the aim of developing strategies to reduce risks. These types include: disruptions, delays, networking and information systems defects, prediction, intellectual properties, logistics, customers (receipt risk), inventory, and capacity. Some findings noted that risks in supply chain are divided to supply (suppliers, production and distribution within the company) and demand (customers including end consumers) [12]. Another research introduced risks in long categories: Strategic, Natural, Political, Economic, Physical, Supply, Market, Transport, Products, Operations, Financial, Information, Management, Planning, Human, Technical, Criminal, Safety and Environment [4].

As it is seen, apparently there are different categorizations of supply chain risks equal to the number of mentioned authors and probably it is caused by their different views. Hence, it can be concluded that presented categorizations of supply chain risks are highly dependent on researcher perspective. But it is clear that despite of observed variety, natures of stated risks in the references are highly similar and we can extract relatively more integrated view of these factors.

According to Project Risk Management in Project Management Institution, Risk Management is as following:

1) Risk Management Planning: first of all we should develop a plan for general issues and whole idea about the risk in our work;
2) Risk Identification: Making a group of expert people to gather and identify the risks;
3) Qualitative and Quantitative Risk Assessment: in this step, the group uses different methods for Risk Analysis, Prioritization and Assessment;
4) Planning to respond the risks: the experts make decision for risk action planning and scheduling in order to react adequately to disruptions;
5) Monitoring and controlling the risks: after doing all above steps, the team starts to monitor and control the risk behavioral factors and if the factors exist from control situation, again the risk management system turns on and does the cycle one more time.

Considering reviewed literature and extracting findings of performed researches before, it is possible to express the risks in supply chain in 6 main categories.

These are supply risk, demand risk, process risk, control and planning risk, competitor-market risk, and social-political risk. These Risk Categories (clusters) contain 33 risk factors, which are showed in Figure 2.

IV. Proposed Methodology

In the supply chain risk management, we faced with two different important parts: 1) Risk Identification, 2) Risk Assessment.

We proposed the below steps for doing these process as well as possible as shown in Fig. 1.

1) Identifying risk factors through survey and classifying it.
2) Assessment of each factor in relation to each other (within and outside of cluster) using FANP.
3) Assessment of supply chain members based on factors, which have been weighted in the previous step with FTOPSIS.

A. Fuzzy Analytic network Process (FANP)

Fuzzy ANP (FANP) algorithm is used to collective decision-making and to determine importance degree of each priority indices. In this method, all inputs and outputs of FANP technique are fuzzy and in contrary to classic FANP defuzzifications are not used but paired comparison matrices between each row criteria are completed by triangular fuzzy numbers. Then values of parameters are calculated in triangular fuzzy numbers formats. In paired comparison of options (criteria), decision maker (expert) can use triangular fuzzy numbers to determine priority degree of options. Paired comparisons matrix completed by triangular fuzzy numbers (l, m, u) to assess priorities of decision maker [5].

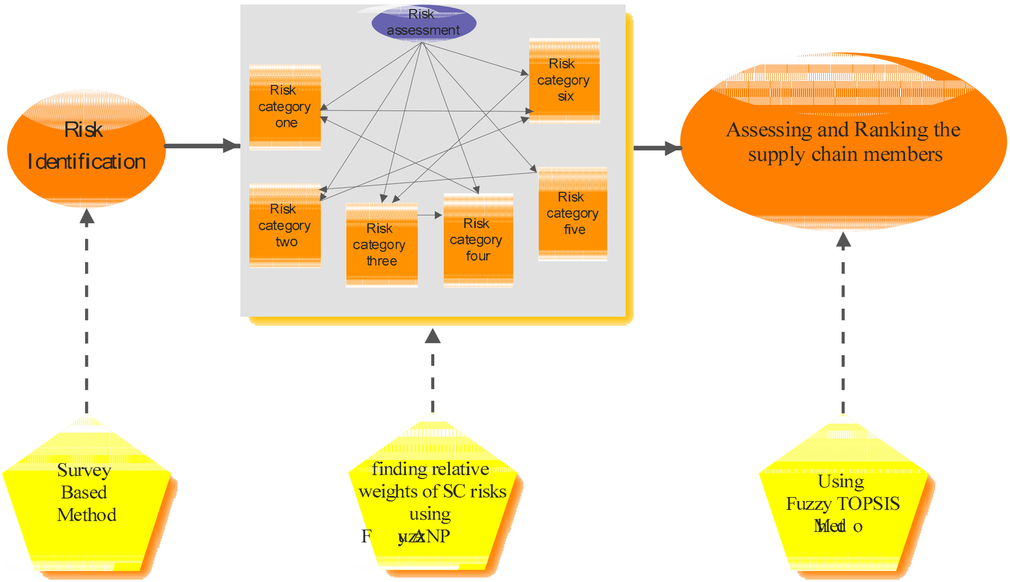

Fig. 1. Magnetization as a function of applied field.

If $\tilde{\mathbf{A}}$ was a paired comparison matrix, it is assumed that its elements are reversed versus main diagonal. Therefore, value of $1/a_{ij}$ can be assigned to element a_{ij}. Finally paired comparison matrix will be as is shown in the following.

$$\tilde{\mathbf{A}} = \begin{bmatrix} (a_{11}^l, a_{11}^m, a_{11}^u) & (a_{12}^l, a_{12}^m, a_{12}^u) & \cdots & (a_{1n}^l, a_{1n}^m, a_{1n}^u) \\ (a_{21}^l, a_{21}^m, a_{21}^u) & (a_{22}^l, a_{22}^m, a_{22}^u) & \cdots & (a_{2n}^l, a_{2n}^m, a_{2n}^u) \\ \vdots & \vdots & \vdots & \vdots \\ (a_{m1}^l, a_{m1}^m, a_{m1}^u) & (a_{m2}^l, a_{m2}^m, a_{m2}^u) & \cdots & (a_{mn}^l, a_{mn}^m, a_{mn}^u) \end{bmatrix}$$

$$\tilde{\mathbf{A}} = \begin{bmatrix} (1,1,1) & (a_{12}^l, a_{12}^m, a_{12}^u) & \cdots & (a_{1n}^l, a_{1n}^m, a_{1n}^u) \\ (\frac{1}{a_{21}^l}, \frac{1}{a_{21}^m}, \frac{1}{a_{21}^u}) & (1,1,1) & \cdots & (a_{2n}^l, a_{2n}^m, a_{2n}^u) \\ \vdots & \vdots & \vdots & \vdots \\ (\frac{1}{a_{m1}^l}, \frac{1}{a_{m1}^m}, \frac{1}{a_{m1}^u}) & (\frac{1}{a_{m2}^l}, \frac{1}{a_{m2}^m}, \frac{1}{a_{m2}^u}) & \cdots & (1,1,1) \end{bmatrix}$$

In this step, a fuzzy geometric mean is used to conclude expert views, which are stated in format of matrix A and paired comparison one. There are many methods to estimate fuzzy weights $\tilde{w}_i$ based on $\tilde{\mathbf{A}}$ using $\tilde{a}_{ij} = \tilde{w}_i / \tilde{w}_j$ in a way that value of $\tilde{w}_i = (w_i^l, w_i^m, w_i^u)$ $(i = 1,2,\dots,n)$ is calculated. The least square logarithm is one of these methods [12] which are the basis of calculating fuzzy weights in the present research. It is possible to calculate triangular fuzzy weights for criteria, options, and so on in this method in a way that the output weights of this method can be used in fuzzy TOPSIS approach to rank options [12]. To calculate weights of above matrices with regard to super matrix W, the following steps have been performed to calculate corresponding weight.

$$W = \begin{bmatrix} 0 & 0 \\ W_{21} & W_{22} \end{bmatrix}$$

And W_{21} is geometric mean of decision making team view concerning paired comparison of ranking indices to the main goal. Matrix W_{21} is filled by geometric mean of experts view regarding paired comparisons of indices against every other ones (control index) as well as using least squares logarithm method to incorporate n tableaus of n criteria. The least squares logarithm method for fuzzy weights is shown as follows.

$$\tilde{w}_k = (w_k^l, w_k^m, w_k^u) \quad k = 1,2,3,\dots,n$$

As

$$w_k^s = \frac{\left(\prod_{j=1}^n a_{kj}^s\right)^{1/n}}{\sum_{i=1}^n \left(\prod_{j=1}^n a_{kj}^m\right)^{1/n}}, s \in \{l, m, u\}$$

Thereafter matrix W_i is calculated using $W_i = W_{22} \times W_{21}$ and fuzzy weights of each priority indices is obtained applying least squares logarithm method.

For having more details about FANP, you can read [8]. ANP method has been preferred to the other multi criteria decision-making methods because of the following items:

1) ANP has a systematic approach to determine priorities and trade off between goals and criteria and importance and weight of criteria relative to each other is

determined based on individual judgments not in an optional or determined way;

2) ANP is able to put all tangible and intangible criteria into the model;

3) ANP has a relatively simple and understandable approach, which is accepted by managers and decision makers easily. As we discussed in supply chain risk management section, always risks in supply chain is related to each other's. So we need a network risk analysis and FANP will do it very well. As an example in a case the relations between clusters are shown in Fig. 2.

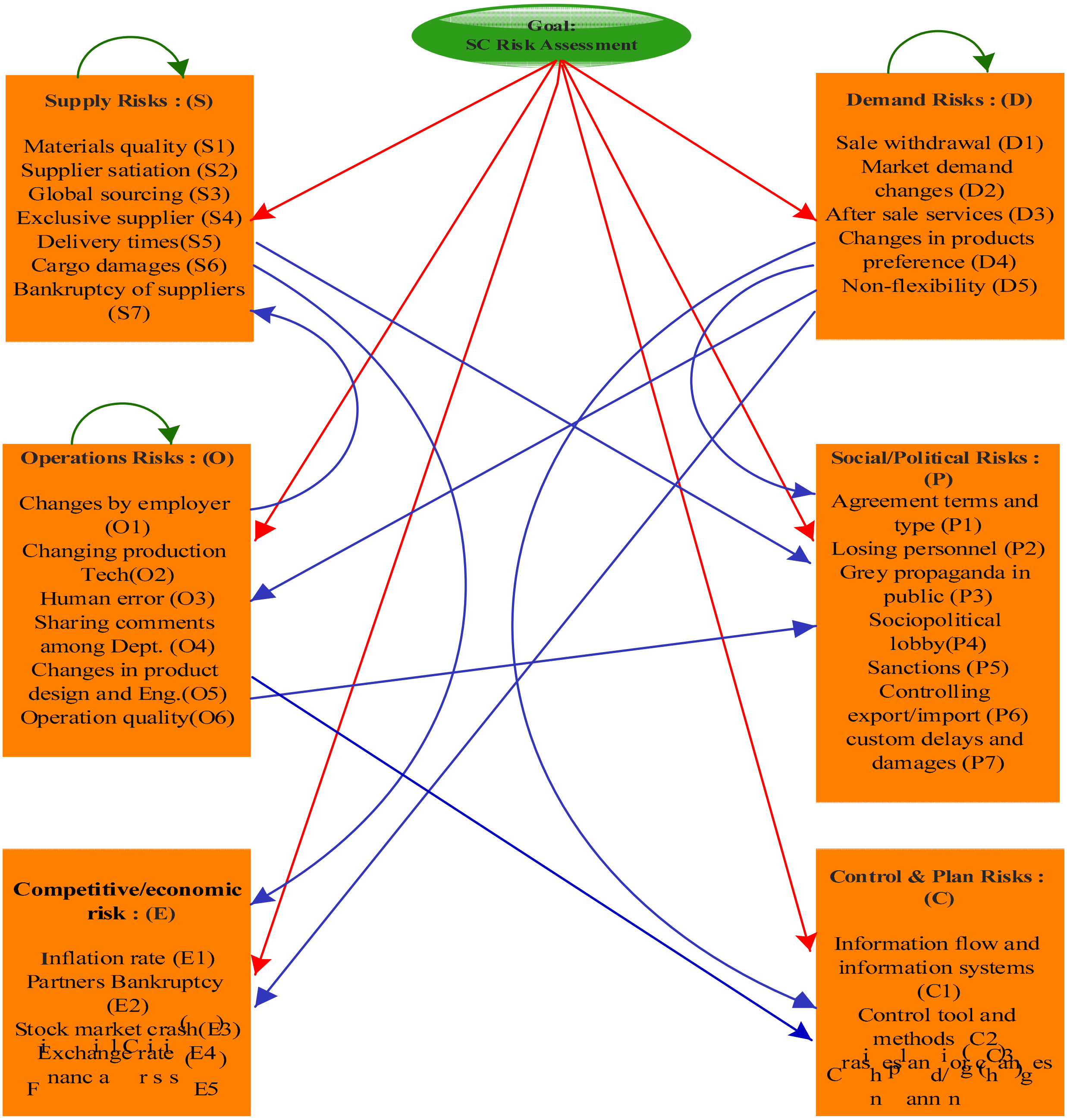

Fig. 2. Network Structure of the Supply Chain Risk Assessment .

B. Fuzzy Technique for Order-Preference by Similarity to Ideal Solution (FTOPSIS)

In 1981, TOPSIS technique was presented by "Huang & Yang" in 2004. TOPSIS technique is based on the fact that selected option has maximum distance to negative ideal solution (worst possible state) [13].

We will attempt to use fuzzy TOPSIS technique that introduced by Chen [14] in order to rank supply chain members. TOPSIS technique has been used because of these four benefits:

1) Having a valid ratiocination to describe logic of individuals truly;

2) Calculating numerical value for best/worst alternatives;

3) Having simple computational process, which is easily programmable in spreadsheets;

4) Multifaceted performance of alternatives in criteria (at least in two faces) is imaginable.

Considering nature of this research, fuzzy TOPSIS introduced by Chen in 1992 has the following steps.

Step 1: assume fuzzy decision making matrix is below.

$$\tilde{\mathbf{D}} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots & \tilde{x}_{2n} \\ . & . & \dots & . \\ . & . & \dots & . \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots & \tilde{x}_{mn} \end{bmatrix}$$

i: number of examined alternatives (m)

j: number of considered criteria (n)

where values of $\tilde{X}_{ij}$ have been calculated multiplying numerical value of alternative i by j th criterion by fuzzy weight of criterion j (which is obtained from fuzzy ANP).

Step 2: descaling decision-making matrix. Here, fuzzy decision making matrix must be converted into a fuzzy descaled matrix R. It is enough to use below formula to obtain matrix R.

$$\tilde{R} = [\tilde{r}_{ij}]_{m\times n}$$

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right)$$

As

$$c_j^* = \max_i c_{ij}$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{ca_j^-}{c_{ij}}\right)$$

$$a_j^- = \min_i a_{ij}$$

Step 3: making fuzzy descaled weighty matrix $\tilde{V}$ assuming vector $\tilde{W}_{ij}$ as input of algorithm in a way that:

$$\tilde{V} = [\tilde{v}_{ij}]_{m\times n}$$

Step 4: specifying fuzzy positive ideal (FPIS, A+) and fuzzy negative ideal (FNIS, A-).

$$A^+ = (\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*)$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-)$$

But we will use FPIS and FNIS introduced by Chen in 1992. These values are:

$$\tilde{v}_j^* = (1,1,1,)$$

$$\tilde{v}_j^- = (0,0,0)$$

Step 5: calculating total distances of each component from FPIS and FNIS.

If (A) and (B) were two fuzzy number in the following form, then the distance between them is calculated using below formula.

$$\tilde{\mathbf{A}} = (a_1, b_1, c_1) \qquad \tilde{\mathbf{B}} = (a_2, b_2, c_2)$$

$$D(A,B) = \sqrt{\frac{1}{3}[(a_2 - a_1)^2 + (b_2 - b_1)^2 + (c_2 - c_1)^2]}$$

Considering above explanations about calculation of the distance between two fuzzy numbers, now it is possible to calculate their distances from FPIS and FNIS.

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij} - \tilde{v}_j^-) \quad i = 1,2,\dots,m$$

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij} - \tilde{v}_j^*) \quad i = 1,2,\dots,m$$

Step 6: calculating relative nearness of i th component to FPIS. This relative nearness is defined as follows.

$$CC_i = \frac{d_i^-}{d_i^- + d_i^*} \qquad i = 1,2,\dots,m$$

Step 7: ranking options.

It is possible to sort (i.e. rank) existent options of assumed problem based on decreasing order of CC_i.

We will have the final ranking of supply chain members after doing these processes.

V. Case Study

MAPNA Boiler Company is chosen to test the proposed model. MAPNA Boiler Engineering & Manufacturing Company (MBC - one of the MAPNA Group's subsidiaries which has been founded in the 1999) is responsible to design and manufacture boiler.

MAPNA Boiler mission is transferring and localization of boiler design, widespread use of manufacturing capacity within the country, and optimal management in the utilization of manufacturing resources under power plant pressure and in the absence of such a pressure. Along with its activities in projects implementation, MAPNA BOILER proceeded technology transfer of know how in design, engineering, procurement, manufacturing, erection, commissioning and maintenance of Heat Recovery Steam Generators (HRSG) from DOOSAN Co. (South Korea). Moreover negotiations and agreements with major European companies such as Macchi- Italy, Thermodesign- Canada- for technology transfer as well as improving technical stand for other types of boilers are underway.

This company has completed more than 25 units of HRSG and on these days, has more than 57 units ordered in around the world.

According to literatures review, the risk factors and relations between Risk Clusters are shown in Figure two. These findings are achieved after interview and observations of MAPNA Boiler supply chain.

we have done the paired-compromised risk categories with the respect to the goal (assessing the supply chain risk) and following the formula and FANP instruction the below matrix is the fuzzy paired comparison of group decision makers for company six risk clusters. This matrix is W_{21}, as we introduced in last section in FANP structure. We developed 38 paired-comparison matrixes. As an example you can see appendix 1.

The top five risk factors are: "Market demand changes (D2)", "Exclusive supplier (S4)", "Exchange rate (E4)", "Global sourcing (S3)" and "Losing personnel (P2)". The results of FANP after paired-comparison, by experts in the company, are as follows in Table II.

TABLE 2: FINAL WEIGHTS OF RISK CATEGORIES

Supply Risk	(1.9614,2.1183,2.2643)
Operations Risks	(2.1950,2.5169,2.8356)
Demand Risks	(2.1113,2.2306,2.3430)
Competitive/economic risk	(2.0331, 2.1401,2.2397)
Control & Plan Risks	(1.9780,2.1998,2.4534)
Social/Political Risks	(1.9845,2.1540,2.3131)

After we find out the weights of risks factors on different clusters, we formed a committee of five decision makers (D1 – D5) to select the most risky partner.

According to supply chain of MAPNA Boiler Company, it has six important partners (members) in its supply chain: AZAR AB Company (M1), MAPNA Manufacturing Plant (M2), Hyosung Company (M3), TAL Industries Company (M4), ASTO Company (M5), Sholeh Khavar Company (M6).

Decision Makers use the below scale for rating the members.

TABLE 3: LINGUISTIC VARIABLES FOR A RATING OF MEMBERS IN FTOPSIS

Very Low (VL)	(0,0,0.25)
Low (L)	(0,0.25,0.5)
Medium (M)	(0.25,0.5,0.75)
High (H)	(0.5,0.75,1)
Very High (VH)	(0.75,1,1)

After evaluation by FTOPSIS, members of the company's supply chain were prioritized in terms of to be risky as shown in appendix 2.

VI. CONCLUSION

Nowadays in the world of advanced industries and complex businesses, the issue of risk management is very important. But in the supply chain of engineering and manufacturing companies this receives more importance because the core of their businesses is based on this process.

Being informed of affecting factors in the risk area helps managers to anticipate these risks and perform operational measures seeking reduction and gradual elimination of them.

Considering the research result which is a pioneer of applying a fully functional model for supply chain management and assessment in its kind inside Iran the following recommendations are reported to improve supply chain performance and its risks management: Creating an integrated system for SCRM (supply chain risk management) and Identifying ways to mitigate or reduce effects of supply chain risk factors applying methods and creating an integrated system.

The Company must form an integrated system in order to manage supply chain risk. After recognizing and assessing risks, identifying ways to restrain and decrease effects of these factors on businesses is most important action. Thus it is recommended that different methods to identify, classify and prioritize the ways to face against supply chain risk are focused in the future projects.

As the research confirms, because of many external factors in Iran such as omitting the subsidies and financial recession, the company, which is so, related to the design and producing inside of Iran is the most risky member in MAPNA Boiler's Supply Chain. Also the fluctuations in employer's order and market changes make a lot of non-predictable risk to the MAPNA Boiler Company.

In the field of risk factors, it should be noted that this study has tried to consider the general categories previously used in other researches, adapt them looking at the examining company, and group in accord to the current conditions. However, doing such works completely requires a large time investment, which is outside the framework of this project.

Meanwhile due to resistance of some companies to review risk factors and their lack of belief in an integrated management of supply chain risk, performing some studies about influential factors on SCRM (including its advantages and disadvantages) will be very useful to corporate managers become more familiar with these issues.

APPENDIX

APPENDIX 1: FUZZY-COMPARISON MATRIXES OF "PLAN & CONTROL" RISKS WITH RESPECT TO "HUMAN ERROR" (O3) FACTOR

	Information flow and IS	Control tool and methods	Changes in planning
Information flow and IS	(1,1,1)	(1.9954,2.3180,2.6329)	(0.2744,0.3655,0.5402)
Control tool and methods	(0.4108,0.4666,0.5420)	(1,1,1)	(0.3470,0.3854,0.4374)
Changes in planning	(2.2742,3.1888,4.1920)	(2.4728,2.8061,3.1174)	(1,1,1)

APPENDIX 2: FINAL RANKING OF SC MEMBERS IN MAPNA BOILER CO. WITH RESP. TO SC RISKS

	di*	di-	ccj	Supply chain Members Rank
Sholeh Khavar Co.	1.253	1.8781	0.5998	1
AZAR AB Co.	1.5496	1.6584	0.5170	2
ASTO Co.	1.5957	1.6095	0.5022	3
TAL Co.	1.7336	1.5401	0.4704	4
MAPNA. Plant	1.9069	1.4943	0.4393	5
Hyosung Co	2.0061	1.4099	0.4127	6

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Mr. Hossein Rikhtehgar Berenji is with Sharif University (Iran) and Multimedia University (Malaysia). He earned his Master of Business Administration in a joint program between above universities. He has a B.S in Industrial Engineering and now works as a consultant (Head of IE department and R&D) at PCG consultants group. One of his publications is about Statistics and Modeling, which is published by Danesh Pajouhan Publication in Iran.

Prof. Dr. Anantharaman is a full professor of Melaka Business School, Multimedia University. He published many papers in different journals about operation managements and supply chain management. He has a brilliant experience in different industries such as oil and gas as a consultant.