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A decision framework for supplier selection under a fuzzy environment

Moslem Alimohammadlou[1], Abbas Bonyani[2*]

1. Associate Professor, Faculty of Economic, Management and Social Science, Shiraz University, Shiraz, Iran
2. MSc. Faculty of Management and Accounting, Allameh Tabataba'i University, Tehran, Iran

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Abstract

Supplier evaluation and selection is one of the most important processes to achieve an efficient supply chain. Nowadays, the business environment has provided causes of emerging a high level of uncertainty and turbulent behavior in supply chains. In most cases, suppliers are considered as the main sources of external risks which provide high levels of disruptions in supply chains; therefore, choosing the appropriate and also resilient suppliers can greatly reduce purchasing costs and delay times and also increase the ability to maintain business in the case of disruption, competitiveness of the company and satisfaction of customers. This study is aimed to identify and investigate the attributes for evaluating the suppliers' resilience from the two aspects, the importance and effectiveness of choosing the resilient suppliers in Iran electronic industries. In this regard, screening, DEMATEL, analytic network process and goal programming have been used furthermore they were performed in the fuzzy environment due to the uncertainty of the nature of all researches. Results showed that some attributes including, human resource management, visibility, and financial strength are the most influential factors. In terms of importance, agility, adaptability, and vulnerability are also the most important factors. At the end, while presenting a case study of the industry and applying goal programming, the ability of the proposed combined model in solving the real-world problems is shown.

Keywords: Supplier selection, Fuzzy Goal Programming, Fuzzy DEMATEL, Fuzzy ANP, Supply Chain Resilience

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* Corresponding Author's E-mail: abbas.bonyani@gmail.com

1. Introduction

The supply chain encompasses all those activities associated with moving goods from the raw-materials stage through to the end user [1]. Today's business environment has created a high level of uncertainty and turbulent behaviors in the supply chains. These turbulent behaviors are the results of some factors such as globalization, an increase in outsourcing level of activities, increased demand fluctuations, a decrease in life cycles of products, a sharp decrease in inventories, and a decrease in the number of suppliers of companies [2,3,4,5]. In addition to the above-mentioned issues, supply chains are facing major challenges and threats such as natural disasters (floods, earthquakes, storms, fires), cyber-attacks, sanctions, disruptions in supply, production and distribution system, and so on. Supply chains are generally subjected to disruptions, and their competitiveness not only depends on the cost reduction, higher quality, delivery time reduction, and higher level of service to customer, but also their ability to prevent and overcome different disruptions endangering their function; therefore, they should be resilient [6].

According to Christopher and Pack, the risk sources of the supply chain are divided into five levels, including, process, control, supply, demand, and environment [7]. In another categorization, the risk sources of the supply chain are categorized into 3 classes including, internal (process) risks, network-related risks (supply and distribution), and external (environmental) risks [8]. Disruptions can be arisen in supply chains in the two forms, internal and external [9]. Meanwhile, suppliers are often considered as the main source of external risks which lead to a wide range of disruptions in the supply chain [10]; because in most industries, costs related to supplying the raw materials, as the main part of production costs, consist of more than70 percent of production costs [11]. Due to the mentioned reasons, choosing the appropriate and also resilient suppliers can greatly reduce the purchasing costs and delay times and also increase the ability to business continuity in case of disruptions (disruptions such as sanction, changing the exchange rate, incompleteness of industry infrastructure, changes in demand and customer expectations, rapid technological changes, poor quality of suppliers' productions, inflexibility of suppliers, and etc.), and consequently, competitiveness of the company and customer satisfaction. As a result, this study is aimed to identify and investigate the attributes for evaluating the suppliers' resilience from the two aspects, the importance and influence of choosing the resilient suppliers in Iran electronic industries.

To this end, it is first necessary to identify and investigate the attributes for evaluating the suppliers' resilience in this industry. In this study, the important attributes related to the suppliers' resilience evaluation are identified by studying the literature review and then, polled by the industry and academia experts using the fuzzy screening questionnaire; finally, most important and most influential attributes related to the evaluation of suppliers' resilience are identified using the fuzzy decision-making techniques.

2. Literature review

Since 2003 to the present that the resilience concept was proposed, various researchers have provided different definitions of it, which in the following most important definitions are referred.

Sheffi proposed the ability and speed of companies to return to their normal level of performance in production and service after a disruption as the resilience of supply chain [12]. Roberto and Perira et al., called the ability of the supply chain in quick response to unexpected event as the resilience of supply chain, so that the operations could be promoted to a previous or even better new level of performance [13]. Yang and Zhou, defined the resilience of supply chain as the ability to respond to disruptions resulted from natural disasters which can be analyzed by regarding the resistance of supply chain its recovery speed [14]. Despite numerous studies and rich background in the area of supplier selection, research in the area of supplier selection in resilient supply chain is limited [15]. Some of the most important researches are referred in the following.

Haldar et al., addressed "chosen suppliers in the resilient chain using a hybrid method based on the AHP, TOPSIS, and QFD". The attributes used for this issue involve two categories of attributes: technical attributes (resilience), including supply chain density, supply chain complexity, responsiveness, node sensitivity, and reengineering, producer attributes, including, buffer capacity, flexibility of supplier sources, and delay time [16].

Sawick evaluated and chosen the suppliers in the case of supply chain disruptions, and allocating orders to the selected suppliers using a mixed-integer programming modeling [17].

Halder et al. provided a strategic and quantitative approach to select the resilient suppliers in a fuzzy environment. They used fuzzy TOPSIS method with triangular and trapezoidal numbers for this issue. Their attributes included quality, product capability, customer satisfaction, and product cost [18].

Azadeh et al. provided a comprehensive approach for selecting the suppliers in the green-resilient supply chain. The examined aspects included finance, quality, service and corporate social responsibility, resilience and environmental. The attributes of resilience aspect were self-organization, reversibility, and flexibility. They used the combined analytic network process and fuzzy dematel methods to determine the weights and relations among the attributes, and also data envelopment analysis method for ranking the suppliers [19].

Torabi et al. addressed the supplier selection and order allocation in a resilient supply chain using the two-step Probabilistic programming. They paid special attention to strengthening the suppliers, contracting with supportive suppliers, and business continuity programs in order to promote the chain [20].

Ahmadi and Mellat-Parast, provided a two-stage mixed-integer programming model in order to select the supplier and allocate order along with the transportation channel selection and providing the contingency plans to reduce the negative effects of disruptions and also minimizing the total network costs in a resilient supply chain [21].

Sahu et al., evaluated and selected the resilient suppliers in a fuzzy environment using the fuzzy VIKOR method. In order to evaluate the resilience of suppliers, they used two classes of public and resilience attributes [22].

Attributes of evaluating the suppliers' resilience: In order to identify and validate the evaluation attributes of suppliers' resilience, 27 attributes have been obtained from the review of theoretical foundations as shown in Table1.

Table 1. Attributes considered for resilient supplier selection in resilient supply chains

Attribute	Relevant literature	Remarks
Visibility	[23],[24],[25],[26], [27],[28],[29]	The ability to see through the entire supply chain (all nodes and links), which helps to identify potential threats
Collaboratio n	[24], [25],[27]	The ability to work effectively with other supply chain entities for mutual benefit, e.g. sharing information and other resources to reduce vulnerability
Flexibility	[23],[24],[25],[26], [27],[29]	The ability of a firm and supply chain to adapt to changing requirements with minimum time and effort
Agility	[2],[24],[29]	The ability to respond quickly to unpredictable changes in demand and/or supply
Velocity	[10]	The pace of flexible adaptations that can determine the recovery speed of the supply chain from a disruption
Vulnerabilit	[10]	Supplier should not be vulnerable to various sources

Attribute	Relevant literature	Remarks
y		of risks. There should be a resilient sales and operations planning process for suppliers to identify and react to sources of vulnerabilities
Research and development	[10]	Suppliers should have a strong R&D wing to incorporate innovations in technology and to adapt with the present market turbulences. In addition, suppliers should work in collaboration with the R&D activities of the firm for risk mitigation
Risk awareness	[10]	Supplier should be aware of various levels of risks, such as risks related with assets, process, organizations and environment. Risk awareness helps them to act in cases of emergency, thus increasing resilience capability of suppliers
Technological capability	[10],[20]	Suppliers must be technologically capable to adapt themselves towards innovations. Incorporating advanced product and process technologies enable suppliers to be resilient enough to adjust with technological turbulence
Risk management culture	[2],[6],[24],[27],[28]	Ensuring that all organizational members embrace supply chain risk management, and this involves, e.g. top management support and firm integration/team work
Safety	[10]	Suppliers must provide their employees with a safe and healthy working environment in order to prevent accidents and injury to health occurring in the course of work or as a result of the operation of the supplier
Supply chain network structure	[12]	Constructing the supply chain network for resilience, e.g. balancing redundancy, efficiency, vulnerabilities, etc.
Adaptive capability	[10]	Supply chain resilience focuses on the system's adaptive capability to deal with temporary disruptive events. The dynamic nature of this adaptive capability allows the supply chain to recover after being disrupted, returning to its original state or achieving a more desirable state of supply chain operations
Trust	[25],[28]	Trust is generally seen as a precondition for risk sharing. Supply chain management is built on a foundation of trust
Risk and revenue sharing	[10]	Risk and revenue sharing is important for long-term focus and collaboration among supply chain partners
Sustainability	[27]	Resilience plays a key role in sustaining dynamic capabilities and maintaining the link between dynamically integrated capabilities and sustainable competitive advantage. Sustainability is a key enabler

Attribute	Relevant literature	Remarks
		for resilience of supply chain
Financial strength	[24]	Financial strength is one of the most important empowering factors of resilience that directly affects the supply and procurement activities
Knowledge management	[12],[23],[25],[28]	Developing knowledge and understanding of supply chain structures (i.e. physical and informational), and the ability to learn from changes as well as educate other entities
Information sharing	[2],[6],[14],[21],[25],[28],[29]	sharing information helps mitigate risk in the supply chain. A key priority for supply chain risk reduction has to be the creation of a supply chain community to enable the exchange of information between members of that community
Redundancy	[6],[14],[21],[24],[26],[27]	The strategic and selective use of spare capacity and inventory that can be used to cope with disruptions, e.g. spare stocks, multiple suppliers and extra facilities
Complexity	[2],[6],[14],[23],[24],[25],[29]	can be measured as a function of the total number of nodes plus the total number of forward, backward, or within-tier flows in the supply chain
Lead time	[2],[6],[29]	Lead time is the time spent from the order to delivery. As the time is longer, the risk of chain vulnerability is increased due to the disruptions
Distance	[2],[14],[26],[29]	Long distances between companies and suppliers increases the risk of disruptions occurrence
Contingency planning	[24],[28]	Anticipating potential events and specifying the measures to deal with supply chain risks and disruptions before they actually occur, e.g. by forecasting and monitoring early warning signals
Demand management	[29]	Mitigating the impact of disruptions by influencing customer choices through, e.g. dynamic pricing, assortment planning and silent product rollovers
Human resource management	[28]	Training the staffs in dealing with dangerous events and creating the multi-task groups
Appropriate supplier selection	[28]	Using selection criteria that can help to minimize disruptions and their impact, such as political stability in suppliers' territories, quality, capabilities (e.g. technological), financial stability, business continuity, reliability, etc.

3. Methodology

The present study, in terms of the purpose, is an applied research and also in terms of data collection is a descriptive-survey method; because it identifies and describes the attributes related to the suppliers' resilience in electronic industries of Iran. On the other hand, a field study was conducted through distributing questionnaires among experts in order to fix and evaluate these attributes from the two aspects of importance and effect. To select experts and professional, targeted sampling method was used; In this regard, the decision group consists of 10 members including 5 experts and managers of the Shiraz Electronic Industries Company and 5 academic members who were the experts in the field of supply chain management.

3.1. Fuzzy screening

Yager introduced a fuzzy screening procedure to select, from a large class of alternatives, a small subset to be further investigated [30]. The fuzzy screening system is a two stage process:

In the first stage, individual experts are asked to provide an evaluation of the alternatives. In the second stage, a methodology is used to aggregate the individual experts' evaluations to obtain an overall linguistic value for each object.

Table 2. scale S for the evaluation of criteria and their degree of importance

OU	S_7	Outstanding
VH	S_6	Very High
H	S_5	High
M	S_4	Medium
L	S_3	Low
VL	S_2	Very Low
N	S_1	None

3.2. Fuzzy DEMATEL

Step 1: Select a group of experts: In this step, it is consulted to the experts who have enough knowledge and experience about the problem in order to obtain judgements.

Step 2: Determine factors and construct fuzzy scale: In this part, significant factors are ascertained in order to analyze and evaluate properly. Then, linguistic variable is used in accordance with five fuzzy scales. Thereafter, corresponding triangular fuzzy members are determined.

Step 3: Obtain evaluation of the group decision-makers: The pair wise comparison is obtained in terms of linguistics variables.

Step 4: Establish normalized direct-relation fuzzy matrix: In the presence of the initial direct-relation matrix, a normalized direct-relation fuzzy matrix is built up.

Step 5: Calculate total-relation fuzzy matrix: After having established normalized direct-relation fuzzy matrix, a total relation fuzzy matrix is calculated by ensuring of $\lim_{w\to\infty} F^w = 0$.

Step 6: Analyze the structural model: After having calculated matrix $\tilde{T}$, $\tilde{r}_i + \tilde{c}_j$ and $\tilde{r}_i - \tilde{c}_j$ are determined. In the formula, $\tilde{r}_i$ and $\tilde{c}_j$ denote the sum of the rows and columns of matrix $\tilde{T}$. While $\tilde{r}_i + \tilde{c}_j$ shows the importance of factor *i*, $\tilde{r}_i - \tilde{c}_j$ denotes the net effect of factor *i*.

Step 7: Defuzzified $\tilde{r}_i + \tilde{c}_j$ and $\tilde{r}_i - \tilde{c}_j$: In this step, $\tilde{r}_i + \tilde{c}_j$ and $\tilde{r}_i - \tilde{c}_j$ are defuzzified by using COA (center of area) defuzzification technique in order to determine BNP (best non-fuzzy performance) values.

Step 8: Build up cause-effect relation diagram: In the last step, the cause and effect relation diagram is depicted by mapping the dataset of $r_i + c_j$ and $r_i - c_j$. The calculation can be done according to the step 6 [31].

3.3. Fuzzy ANP[1]

In this approach, the pair-wise comparison matrices are formed between various attributes of each level with the help of triangular fuzzy numbers. The FANP can easily accommodate the interrelationships existing among the functional activities. The concept of super matrices is employed to obtain the composite weights that overcome the existing interrelationships. The values of parameters such are transformed into triangular fuzzy numbers and are used to calculate fuzzy values.

The logarithmic least squares method for calculating triangular fuzzy weights can be given as follows [32]:

$$w_k^s = \frac{\left(\prod_{j=1}^{n} a_{kj}^s\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n} a_{ij}^m\right)^{1/n}}, \quad s \in \{l, m, u\} \qquad \tilde{w}_k = (w_k^l, w_k^m, w_k^u) \quad k = 1,2,3,\ldots,n \tag{1}$$

In order to calculate the final weigh of each level's components (w_i^*), the multiplication of eigenvector matrix of internal relations in eigenvector of that level should be multiplied by the final weight the higher level . If there is no any w_{ii} matrix for a level, then, it is necessary to replace it with a same degree unit matrix.

$$W_i^* = W_{ii} \times W_{i(i-1)} \times W_{i-1}^* \quad , \quad W_i^* = I \times W_{i(i-1)} \times W_{i-1}^* \tag{2}$$

3.4. Fuzzy goal programming

Fuzzy goal programming is an extension of conventional goal programming to solve decision problems with multiplicity of objectives in an imprecise environment. In this approach, instead of measuring achievement of fuzzy objective values directly, achievement of membership values of objectives to the possible extent to the highest degree by minimizing under-deviations is taken into account in a solution search process. In this paper, the Zimmerman FGP model is used. Modeling of this method is as follows [33]:

$$\max z = \sum_{j=1}^{Q} wj\lambda j$$

$$\begin{aligned} &\text{St:} \\ &\lambda_j \leq \mu_{zj}(x) \qquad j = 1.2. \dots . q \qquad (\text{objective functions}) \\ &\gamma_r \leq \mu_{gr}(x) \qquad r = 1.2. \dots . h \qquad (\text{fuzzy constraints}) \\ &g_p(x) \leq b_p \qquad p = h + 1. \dots . m \qquad (\text{unfuzzy constraints}) \end{aligned} \tag{3}$$

Membership function for maximization goals:

$$\mu_{zj}(X) = \begin{cases} 1 & zj \geq zj^+ \\ \dfrac{zj(x) - zj^-}{zj^+ - zj^-} & zj^- \leq zj(x) \leq zj^+ \\ 0 & zj \leq zj^- \end{cases} \tag{4}$$

Membership function for minimization goals:

$$\mu_{zj}(X) = \begin{cases} 1 & zj \le zj^- \\ \dfrac{zj^+ - zj(x)}{zj^+ - zj^-} & zj^- \le zj(x) \le zj^+ \\ 0 & zj \ge zj^+ \end{cases} \quad (5)$$

Membership function for fuzzy constraints:

$$\mu_{gr}(X) = \begin{cases} 1 & g_r(x) \le b_r \\ 1 - (g_r(x) - br)/dr & br \le g_r(x) \le b_r + d_r \\ 0 & g_r(x) \ge b_r + d_r \end{cases} \quad (6)$$

4. Data analysis

4.1 selecting the supplier resilience attributes using the fuzzy screening

In order to select the evaluation attributes of suppliers' resilience, 27 attributes obtained from the review of theoretical foundations (Table 1), were entered into the fuzzy screening questionnaire, and experts were asked answer the questions in accordance with the description of this method. Based the default determined by the experts, if the total score of a criterion is OU, it is selected. Finally, after analyzing the data, of fuzzy screening questionnaire, 15 attributes were confirmed and selected (Table 3).

A1 : Agility
A2 : Redundancy
A3 : Visibility
A4 : Information sharing
A5 : Trust
A6 : Collaboration
A7 : Flexibility
A8: Financial strength
A9 : Lead time
A10 : Adaptive capability
A11: Risk management culture
A12 : Demand management
A13 : Sustainability
A14 : Human resource management
A15 : Vulnerability

Table 3. Results of fuzzy screening

Result	u_i	OU	VH	H	H	M	M	L	VL	VL	N	Attribute
×	H	H	H	H	H	H	H	H	M	M	L	Contingency planning
		H	H	H	H	M	M	L	VL	VL	N	MIN
×	VH	VH	VH	VH	VH	H	H	H	H	M	M	Complexity
		VH	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	OU	VH	VH	VH	H	H	H	H	M	Vulnerability

Result	u_i	OU	VH	H	H	M	M	L	VL	VL	N	Attribute
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
×	H	H	H	H	H	M	M	M	M	M	L	Knowledge management
		H	H	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	OU	OU	OU	OU	OU	VH	VH	VH	H	Agility
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
×	H	H	H	H	H	M	M	M	M	M	M	Risk awareness
		H	H	H	H	M	M	L	VL	VL	N	MIN
×	H	H	H	H	H	H	H	M	M	M	L	Distance
		H	H	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	VH	VH	VH	VH	VH	H	H	H	H	Information sharing
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
×	VH	VH	VH	H	H	H	H	M	M	M	M	Velocity
		VH	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	OU	VH	VH	VH	H	H	H	H	H	Redundancy
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	VH	VH	VH	H	H	H	H	H	M	Sustainability
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	OU	VH	VH	VH	H	H	H	H	M	Trust
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	OU	OU	VH	VH	VH	H	H	H	M	Financial strength
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
×	VH	VH	VH	VH	VH	H	H	H	M	M	M	Supply chain structure
		VH	VH	H	H	M	M	L	VL	VL	N	MIN
×	H	H	H	H	H	H	M	M	M	L	L	Safety
		H	H	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	VH	VH	VH	VH	M	M	M	M	M	Visibility
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	OU	VH	VH	VH	VH	VH	VH	H	H	Demand management
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
×	VH	VH	VH	VH	VH	VH	H	H	H	H	H	Appropriate supplier selection
		VH	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	OU	OU	VH	VH	H	H	H	H	M	Lead time
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	OU	VH	VH	VH	VH	VH	VH	H	H	Human resource management

Result	u_i	OU	VH	H	H	M	M	L	VL	VL	N	Attribute
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
×	VH	VH	VH	H	H	H	H	H	M	M	M	Research and development
		VH	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	OU	VH	VH	VH	VH	H	H	H	M	Collaboration
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
×	VH	VH	VH	H	H	H	H	H	M	M	M	Technological capability
		VH	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	VH	VH	VH	H	H	H	H	H	H	Adaptive capability
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
×	VH	VH	VH	VH	VH	VH	H	H	H	H	M	Risk and revenue sharing
		VH	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	VH	VH	VH	VH	H	H	H	H	H	Risk management culture
		OU	VH	H	H	M	M	L	VL	VL	N	MIN
✓	OU	OU	OU	OU	OU	VH	VH	VH	VH	H	H	Flexibility
		OU	VH	H	H	M	M	L	VL	VL	N	MIN

4.2. Determining the most influential attributes using the Fuzzy DEMATEL:

at this step, the direct effect of attributes on each other is determined using the DEMATEL questionnaire, and a fuzzy direct-relation matrix is formed from the average of expert’s opinions. After normalizing the fuzzy direct-relation matrix, the Fuzzy total-relation matrix can be obtained (see Table 4).

Table 4. Fuzzy total-relation matrix

A_{15}	A_{14}	A_{13}	A_{12}	A_{11}	A_{10}	A_9	A_8	A_7	A_6	A_5	A_4	A_3	A_2	A_1	
(0.076,0.120,0.279)	(0.000,0.000,0.077)	(0.000,0.000,0.083)	(0.005,0.018,0.145)	(0.006,0.017,0.158)	(0.050,0.092,0.255)	(0.072,0.110,0.238)	(0.000,0.000,0.076)	(0.069,0.104,0.217)	(0.005,0.017,0.146)	(0.005,0.017,0.147)	(0.003,0.009,0.123)	(0.001,0.003,0.110)	(0.000,0.002,0.103)	(0.006,0.017,0.133)	A_1
(0.082,0.138,0.319)	(0.000,0.000,0.089)	(0.000,0.000,0.096)	(0.045,0.085,0.228)	(0.070,0.110,0.251)	(0.075,0.126,0.297)	(0.028,0.075,0.242)	(0.000,0.000,0.087)	(0.008,0.025,0.176)	(0.006,0.023,0.170)	(0.021,0.060,0.207)	(0.005,0.016,0.144)	(0.001,0.006,0.129)	(0.001,0.007,0.099)	(0.044,0.083,0.241)	A_2
(0.091,0.171,0.398)	(0.000,0.000,0.110)	(0.017,0.041,0.158)	(0.048,0.099,0.277)	(0.074,0.128,0.306)	(0.060,0.131,0.361)	(0.058,0.120,0.324)	(0.000,0.000,0.109)	(0.051,0.102,0.285)	(0.024,0.075,0.256)	(0.024,0.075,0.258)	(0.022,0.062,0.221)	(0.003,0.014,0.143)	(0.018,0.051,0.192)	(0.074,0.127,0.305)	A_3
(0.095,0.173,0.391)	(0.000,0.000,0.108)	(0.001,0.003,0.120)	(0.072,0.122,0.279)	(0.077,0.129,0.302)	(0.085,0.154,0.362)	(0.038,0.101,0.300)	(0.000,0.000,0.107)	(0.053,0.105,0.283)	(0.048,0.097,0.272)	(0.025,0.075,0.252)	(0.009,0.028,0.160)	(0.043,0.077,0.223)	(0.003,0.015,0.154)	(0.077,0.131,0.302)	A_4
(0.097,0.181,0.401)	(0.000,0.000,0.111)	(0.001,0.003,0.123)	(0.030,0.086,0.261)	(0.083,0.141,0.313)	(0.089,0.164,0.373)	(0.034,0.101,0.306)	(0.000,0.000,0.109)	(0.031,0.087,0.269)	(0.073,0.124,0.286)	(0.012,0.043,0.201)	(0.074,0.116,0.254)	(0.047,0.082,0.230)	(0.019,0.054,0.195)	(0.058,0.116,0.305)	A_5
(0.099,0.183,0.403)	(0.000,0.000,0.112)	(0.001,0.003,0.123)	(0.030,0.086,0.262)	(0.083,0.141,0.314)	(0.090,0.166,0.374)	(0.036,0.104,0.308)	(0.000,0.000,0.110)	(0.033,0.089,0.271)	(0.013,0.044,0.201)	(0.072,0.124,0.289)	(0.074,0.116,0.255)	(0.047,0.082,0.231)	(0.019,0.054,0.195)	(0.080,0.138,0.312)	A_6
(0.076,0.120,0.279)	(0.000,0.000,0.077)	(0.000,0.000,0.083)	(0.005,0.018,0.145)	(0.006,0.017,0.158)	(0.050,0.092,0.255)	(0.072,0.110,0.238)	(0.000,0.000,0.076)	(0.009,0.024,0.130)	(0.005,0.017,0.146)	(0.005,0.017,0.147)	(0.003,0.009,0.123)	(0.001,0.003,0.110)	(0.000,0.002,0.103)	(0.066,0.098,0.220)	A_7
(0.029,0.089,0.288)	(0.000,0.017,0.103)	(0.017,0.042,0.134)	(0.005,0.024,0.169)	(0.024,0.069,0.225)	(0.026,0.079,0.266)	(0.022,0.069,0.237)	(0.000,0.000,0.063)	(0.004,0.023,0.174)	(0.003,0.022,0.169)	(0.004,0.024,0.172)	(0.002,0.029,0.157)	(0.017,0.046,0.166)	(0.064,0.092,0.186)	(0.021,0.063,0.220)	A_8
(0.059,0.118,0.329)	(0.000,0.000,0.093)	(0.000,0.000,0.100)	(0.045,0.086,0.237)	(0.050,0.092,0.257)	(0.054,0.107,0.305)	(0.011,0.038,0.194)	(0.000,0.000,0.091)	(0.045,0.085,0.242)	(0.046,0.086,0.238)	(0.046,0.086,0.240)	(0.008,0.022,0.157)	(0.004,0.012,0.141)	(0.002,0.011,0.131)	(0.010,0.032,0.199)	A_9
(0.084,0.147,0.345)	(0.000,0.000,0.095)	(0.000,0.001,0.103)	(0.024,0.067,0.222)	(0.051,0.095,0.263)	(0.018,0.055,0.234)	(0.013,0.045,0.227)	(0.000,0.000,0.094)	(0.047,0.090,0.251)	(0.046,0.088,0.244)	(0.045,0.086,0.244)	(0.047,0.083,0.219)	(0.006,0.016,0.148)	(0.002,0.010,0.134)	(0.028,0.076,0.244)	A_{10}
(0.069,0.110,0.263)	(0.000,0.000,0.073)	(0.000,0.000,0.079)	(0.003,0.015,0.137)	(0.003,0.016,0.127)	(0.045,0.084,0.241)	(0.020,0.055,0.196)	(0.000,0.000,0.072)	(0.003,0.013,0.140)	(0.003,0.031,0.153)	(0.003,0.031,0.154)	(0.002,0.011,0.118)	(0.000,0.005,0.106)	(0.000,0.003,0.098)	(0.001,0.011,0.145)	A_{11}
(0.047,0.089,0.259)	(0.000,0.000,0.074)	(0.000,0.000,0.079)	(0.004,0.016,0.115)	(0.005,0.016,0.150)	(0.007,0.041,0.201)	(0.068,0.104,0.229)	(0.000,0.000,0.072)	(0.004,0.015,0.141)	(0.003,0.013,0.136)	(0.004,0.014,0.139)	(0.001,0.005,0.114)	(0.000,0.002,0.105)	(0.017,0.042,0.136)	(0.018,0.049,0.183)	A_{12}
(0.048,0.089,0.257)	(0.000,0.000,0.073)	(0.000,0.000,0.056)	(0.003,0.014,0.136)	(0.007,0.019,0.151)	(0.009,0.026,0.185)	(0.005,0.018,0.162)	(0.000,0.000,0.072)	(0.003,0.012,0.139)	(0.044,0.077,0.196)	(0.044,0.077,0.197)	(0.006,0.015,0.121)	(0.004,0.011,0.112)	(0.002,0.007,0.102)	(0.006,0.017,0.150)	A_{13}
(0.077,0.161,0.407)	(0.000,0.000,0.091)	(0.001,0.004,0.127)	(0.014,0.047,0.231)	(0.061,0.121,0.317)	(0.068,0.145,0.379)	(0.060,0.127,0.337)	(0.000,0.000,0.113)	(0.080,0.138,0.309)	(0.053,0.107,0.291)	(0.051,0.105,0.292)	(0.074,0.120,0.264)	(0.071,0.109,0.246)	(0.003,0.015,0.162)	(0.062,0.121,0.314)	A_{14}
(0.007,0.027,0.176)	(0.000,0.000,0.073)	(0.000,0.000,0.079)	(0.019,0.053,0.174)	(0.004,0.017,0.151)	(0.043,0.081,0.239)	(0.042,0.077,0.217)	(0.000,0.000,0.072)	(0.004,0.015,0.141)	(0.004,0.031,0.153)	(0.004,0.031,0.154)	(0.002,0.011,0.118)	(0.000,0.005,0.106)	(0.000,0.005,0.100)	(0.002,0.013,0.147)	A_{15}

Influential network relations map (INRM): In this step, the sum of fuzzy rows and the sum of fuzzy columns are used to derive vector $\tilde{s}$ and vector $\tilde{r}$ respectively. Then, the horizontal axis vector ($\tilde{s} + \tilde{r}$), called Prominence, is formed by adding $\tilde{s}$ to $\tilde{r}$, which indicates the level of importance of the criterion. Similarly, the vertical axis vector ($\tilde{s} - \tilde{r}$), called Relation, is formed by subtracting ***s*** from ***r***, which may divide criteria into a cause group and effect group. When ($\tilde{s} - \tilde{r}$) is positive, the criterion belong to the cause group; otherwise, it belong to the effect group. Therefore, the INRM can be derived by mapping the dataset of ($\tilde{s} + \tilde{r}$, $\tilde{s} - \tilde{r}$), which provides valuable insights for making decisions (see Table 5).

Table 5. Sum of influences given and received on criteria

Fuzzy			Crisp	
	$\tilde{s}_i + \tilde{r}_i$	$\tilde{s}_i - r_i$	$(\tilde{s}_i + \tilde{r}_i)^{def}$	$(\tilde{s}_i - \tilde{r}_i)^{def}$
A1	(0.854,1.619,5.713)	(-3.120,-0.564,1.738)	2.451	-0.628
A2	(0.538,1.124,4.866)	(-1.705,0.384,2.623)	1.913	0.422
A3	(0.809,1.666,6.011)	(-1.741,0.722,3.461)	2.538	0.791
A4	(0.957,1.862,6.165)	(-1.923,0.558,3.285)	2.712	0.619
A5	(1.015,2.165,6.831)	(-2.445,0.431,3.371)	3.044	0.447
A6	(1.055,2.184,6.816)	(-2.379,0.478,3.381)	3.06	0.49
A7	(0.747,1.454,5.461)	(-2.868,-0.400,1.846)	2.279	-0.455
A8	(0.239,0.690,4.054)	(-1.083,0.690,2.732)	1.418	0.757
A9	(0.961,2.031,6.712)	(-3.375,-0.477,2.376)	2.934	-0.488
A10	(1.182,2.401,7.394)	(-3.916,-0.682,2.297)	3.345	-0.746
A11	(0.756,1.516,5.542)	(-3.291,-0.744,1.495)	2.333	-0.821
A12	(0.531,1.244,5.153)	(-2.842,-0.433,1.780)	2.043	-0.482
A13	(0.216,0.482,3.651)	(-1.364,0.283,2.070)	1.208	0.318
A14	(0.677,1.336,5.240)	(-0.683,1.303,3.880)	2.147	1.451
A15	(1.168,2.280,6.891)	(-4.660,-1.550,1.063)	3.155	-1.674

Given the INRM, it can be expressed that attributes including, human resource management, visibility, and financial strength are the most influential factors (see Fig. 1).

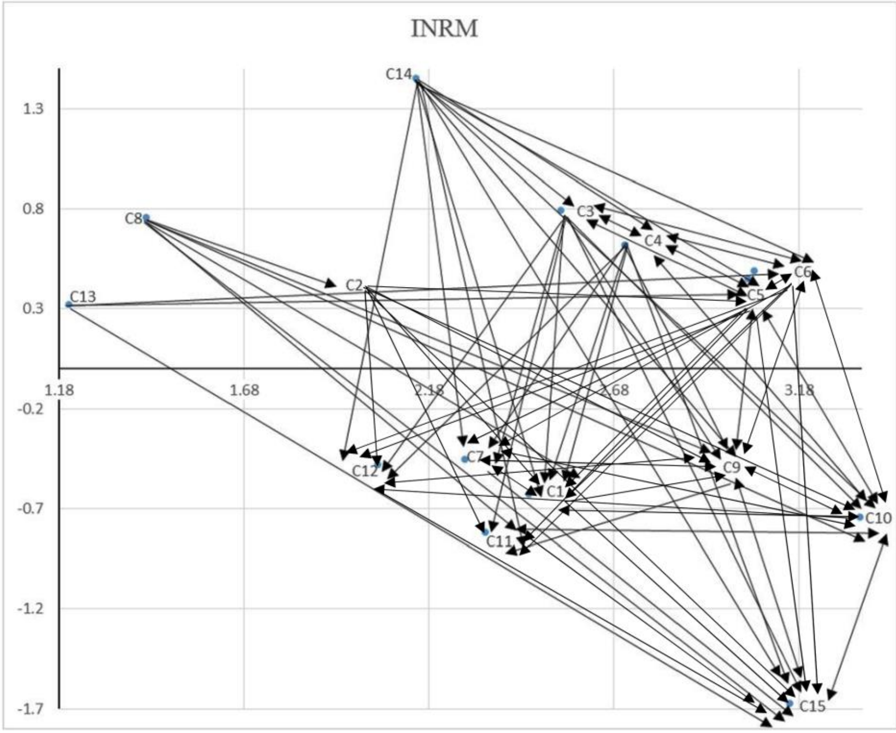

Fig 1. Influential network relations map (INRM)

The network analytic method made it possible for decision maker to build a network instead of hierarchy. This made the investigation of internal relation between the elements possible. The relative importance of the elements of each cluster was similar to the hierarchy analysis method based on pair-wise comparison. But, determining the relation in network structure or determining the mutual dependency degree between the criteria is the most important issue in network analysis method. The internal relations are evaluated by DEMATEL technique. The benefit of this method to network analytic technique is its transparency in reflecting the mutual relations between a wide set of elements as the experts can give their comments in relation to the effects (direction and severity of the effects) between the factors. It can be said that final matrix of DEMATEL technique (internal relations matrix) formed a part of super-matrix. DEMATEL technique doesn't act separately and it acts as a sub-system of a great system as ANP.

4.3. Identifying the most important attributes by F-ANP

Pairwise comparison matrix: In this step, the dependency between attributes is defined based on the network relationships map obtained from the DEMATEL, and accordingly, questionnaires of pair-wise comparisons were designed and distributed among experts. In order to integrate the experts' opinions, geometric mean is taken from the pairwise comparisons of respondents. In the end column of the matrix, the eigenvector of fuzzy weights is achieved using the logarithmic leas squares method. Table 6 shows the pairwise comparisons of attributes with regard to the goal. The other pairwise comparisons with regard to each criterion is calculated in the same way. The consistency of all the comparisons was checked using the Gogus and Boucher method.

Table 6. Pairwise comparisons of attributes with respect to goal

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	*W*
A1	(1,1,1)	(1.000,1.225,1.225)	(1.000,1.732,1.732)	(1.000,1.732,1.732)	(1.732,2.646,2.828)	(1.000,1.732,1.732)	(1.000,1.732,1.732)	(3.000,4.243,4.743)	(3.873,4.975,5.477)	(1.000,1.225,1.225)	(1.000,1.732,1.732)	(3.000,3.742,4.243)	(3.873,4.975,5.477)	(3.000,3.742,4.243)	(1.000,1.732,1.732)	(0.09, 0.129, 0.134)
A2	(0.816,0.816,1.000)	(1,1,1)	(1.000,1.225,1.225)	(1.000,1.225,1.225)	(1.000,1.732,1.732)	(1.000,1.225,1.225)	(1.000,1.225,1.225)	(3.000,3.742,4.243)	(3.000,4.243,4.743)	(0.816,0.816,1.000)	(1.000,1.225,1.225)	(1.732,2.646,2.828)	(3.000,4.243,4.743)	(1.732,2.646,2.828)	(1.000,1.225,1.225)	(0.076,0.096,0.102)
A3	(0.577,0.577,1.000)	(0.816,0.816,1.000)	(1,1,1)	(1.000,1.225,1.225)	(1.000,1.225,1.225)	(1.000,1.225,1.225)	(1.000,1.225,1.225)	(1.732,2.646,2.828)	(3.000,3.742,4.243)	(0.577,0.577,1.000)	(1.000,1.225,1.225)	(1.000,1.732,1.732)	(3.000,3.742,4.243)	(1.000,1.732,1.732)	(1.000,1.225,1.225)	(0.064,0.079,0.088)
A4	(0.577,0.577,1.000)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(1,1,1)	(1.000,1.225,1.225)	(1.000,1.225,1.225)	(1.000,1.225,1.225)	(1.732,2.646,2.828)	(3.000,3.742,4.243)	(0.577,0.577,1.000)	(1.000,1.225,1.225)	(1.000,1.732,1.732)	(3.000,3.742,4.243)	(1.000,1.732,1.732)	(1.000,1.225,1.225)	(0.063,0.077,0.087)
A5	(0.354,0.378,0.577)	(0.577,0.577,1.000)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(1,1,1)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(1.000,1.732,1.732)	(1.732,2.646,2.828)	(0.354,0.378,0.577)	(0.816,0.816,1.000)	(1.000,1.225,1.225)	(1.732,2.646,2.828)	(1.000,1.225,1.225)	(0.816,0.816,1.000)	(0.048,0.055,0.066)

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	*W*
A6	(0.577,0.577,1.000)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(1,1.225,1.225)	(1,1,1)	(1.000,1.225,1.225)	(1.732,2.646,2.828)	(3.000,3.742,4.243)	(0.577,0.577,1.000)	(1.000,1.225,1.225)	(1.000,1.732,1.732)	(3.000,3.742,4.243)	(1.000,1.732,1.732)	(1.000,1.225,1.225)	(0.062,0.075,0.086)
A7	(0.577,0.577,1.000)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(1.000,1.225,1.225)	(0.816,0.816,1.000)	(1,1,1)	(1.732,2.646,2.828)	(3.000,3.742,4.243)	(0.577,0.577,1.000)	(1.000,1.225,1.225)	(1.000,1.732,1.732)	(3.000,3.742,4.243)	(1.000,1.732,1.732)	(1.000,1.225,1.225)	(0.061,0.073,0.085)
A8	(0.211,0.236,0.333)	(0.236,0.267,0.333)	(0.354,0.378,0.577)	(0.354,0.378,0.577)	(0.577,0.577,1.000)	(0.354,0.378,0.577)	(0.354,0.378,0.577)	(1,1,1)	(1.000,1.225,1.225)	(0.211,0.236,0.333)	(0.354,0.378,0.577)	(0.816,0.816,1.000)	(1.000,1.225,1.225)	(0.816,0.816,1.000)	(0.354,0.378,0.577)	(0.027,0.029,0.038)
A9	(0.183,0.201,0.258)	(0.211,0.236,0.333)	(0.236,0.267,0.333)	(0.236,0.267,0.333)	(0.354,0.378,0.577)	(0.236,0.267,0.333)	(0.236,0.267,0.333)	(0.816,0.816,1.000)	(1,1,1)	(0.183,0.201,0.258)	(0.236,0.267,0.333)	(0.577,0.577,1.000)	(1.000,1.225,1.225)	(0.577,0.577,1.000)	(0.236,0.267,0.333)	(0.02,0.022,0.028)
A10	(0.816,0.816,1.000)	(1.000,1.225,1.225)	(1.000,1.732,1.732)	(1.000,1.732,1.732)	(1.732,2.646,2.828)	(1.000,1.732,1.732)	(1.000,1.732,1.732)	(3.000,4.243,4.743)	(3.873,4.975,5.477)	(1,1,1)	(1.000,1.732,1.732)	(3.000,3.742,4.243)	(3.873,4.975,5.477)	(3.000,3.742,4.243)	(1.000,1.732,1.732)	(0.089,0.126,0.133)
A11	(0.577,0.577,1.000)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(1.000,1.225,1.225)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(1.732,2.646,2.828)	(3.000,3.742,4.243)	(0.577,0.577,1.000)	(1,1,1)	(1.000,1.732,1.732)	(3.000,3.742,4.243)	(1.000,1.732,1.732)	(1.000,1.225,1.225)	(0.061,0.071,0.083)
A12	(0.236,0.267,0.333)	(0.354,0.378,0.577)	(0.577,0.577,1.000)	(0.577,0.577,1.000)	(0.816,0.816,1.000)	(0.577,0.577,1.000)	(0.577,0.577,1.000)	(1.000,1.225,1.225)	(1.000,1.732,1.732)	(0.236,0.267,0.333)	(0.577,0.577,1.000)	(1,1,1)	(1.000,1.732,1.732)	(1.000,1.225,1.225)	(0.577,0.577,1.000)	(0.035,0.04,0.053)
A13	(0.183,0.201,0.258)	(0.211,0.236,0.333)	(0.236,0.267,0.333)	(0.236,0.267,0.333)	(0.354,0.378,0.577)	(0.236,0.267,0.333)	(0.236,0.267,0.333)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(0.183,0.201,0.258)	(0.236,0.267,0.333)	(0.577,0.577,1.000)	(1,1,1)	(0.577,0.577,1.000)	(0.236,0.267,0.333)	(0.02, 0.021,0.028)
A14	(0.236,0.267,0.3	(0.354,0.378,0.5	(0.577,0.577,1.0	(0.577,0.577,1.0	(0.816,0.816,1.0	(0.577,0.577,1.0	(0.577,0.577,1.0	(1.000,1.225,1	(1.000,1.732,1	(0.236,0.267,0.3	(0.577,0.577,1.0	(0.816,0.816,1.0	(1.000,1.732,1	(1,1,1)	(0.577,0.577,1.0	(0.035,0.039,0.0

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	*W*
	33)	77)	00)	00)	00)	00)	00)	.225)	.732)	33)	00)	00)	.732)		00)	53)
A15	(0.577,0.577,1.000)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(1.000,1.225,1.225)	(0.816,0.816,1.000)	(0.816,0.816,1.000)	(1.732,2.646,2.828)	(3.000,3.742,4.243)	(0.577,0.577,1.000)	(0.816,0.816,1.000)	(1.000,1.732,1.732)	(3.000,3.742,4.243)	(1.000,1.732,1.732)	(1,1,1)	(0.06, 0.069, 0.082)
CR^g =0.029 Consistent ⟹ CR^m =0.004 ⟸																

Final weights: Table 7 shows the final weights of the attributes with respect to goal that accordingly, agility, Adaptive capability, and vulnerability are the most important attributes.

Table 7. final weights of the attributes with respect to goal

	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
Fuzzy weights	(0.083,0.127, 0.143)	(0.061,0.084, 0.096)	(0.064,0.09, 0.107)	(0.058,0.082, 0.096)	(0.056,0.075, 0.094)	(0.057,0.075, 0.093)	(0.048,0.062, 0.075)	(0.022,0.026, 0.036)	(0.024,0.03, 0.042)	(0.073,0.105, 0.122)	(0.041,0.049, 0.063)	(0.031,0.039, 0.054)	(0.013,0.014, 0.019)	(0.034,0.043, 0.061)	(0.072,0.10, 0.123)
Crisp weights	0.122	0.082	0.089	0.08	0.075	0.075	0.062	0.027	0.031	0.103	0.05	0.04	0.015	0.044	0.099

4.4. Resilient supplier selection by FGP[2]

In this section, a real case study is addressed at Shiraz Electronics industries. Shiraz electronic industries Company is considered as one of the professional companies of Iran electronic industries in the fields of research, design and manufacturing in different areas of electronic technology including Radar, electronic warfare, electronics weapons and etc. In this study, 20 suppliers are considered for an electronic part applied in one of the strategic products of the company, which name of parts, product, and suppliers are not mentioned for security reasons.

Decision Matrix: the required information about the suppliers have been obtained by distributing the questionnaire among 5 managers and experts of relevant department in this company (each supplier is assigned score 1-10 based on the obtained resilience attributes from the previous steps) and finally, mean of the opinions is calculated and the decision matrix is formed in accordance with Table 8.

Table 8. Decision Matrix

Attributes	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
Weight	0.122	0.082	0.089	0.08	0.075	0.075	0.062	0.027	0.031	0.103	0.05	0.04	0.015	0.044	0.099
Min/Max	max	max	max	max	max	max	max	max	min	max	max	max	max	max	min
S1	5.4	7.4	5.8	6.4	7.6	6.6	5.4	6.8	4.8	6.6	7.4	5.8	6.2	7.4	5.2
S2	3.6	5.2	4.4	5.2	6.2	4.8	3.6	5.4	6.2	5.2	4.8	5.2	4.2	5.4	6.4
S3	7.8	8.2	7.2	7.6	8.2	8.4	7.2	7.4	2.8	7.6	8.2	7.4	7.4	8.2	2.6
S4	2.2	3.4	1.8	2.4	2.2	1.6	1.4	1.8	9.2	2.2	2.2	2.2	1.8	2.2	9.6
S5	9.8	9.2	8.8	8.6	9.4	8.4	9.8	8.4	2.8	9.2	9.2	9.6	9.4	9.4	2.2
S6	2.8	6.6	4.8	4.4	5.6	4.2	3.4	4.4	7.8	4.6	3.6	4.6	3.8	4.4	7.2
S7	2.4	3.8	2.8	3.2	3.6	3.4	2.8	3.2	8.6	2.6	2.2	3.2	2.6	2.6	9.2
S8	8.2	8.4	7.6	8.2	8.2	9.4	8.6	8.4	3.2	9.4	9.6	8.2	8.6	9.2	3.2
S9	1.6	2.6	1.6	3.2	1.8	2.6	2.4	2.4	9.2	1.8	2.4	1.8	2.2	2.4	9.4
S10	3.2	6.4	4.2	4.8	5.8	3.8	3.2	4.4	7.2	4.4	5.2	4.6	5.2	4.8	7.4
S11	7.6	7.2	6.6	6.6	7.8	7.6	7.8	7.4	3.6	8.2	7.2	6.4	7.8	7.2	3.6
S12	8.6	8.8	8.2	9.2	8.8	8.4	8.2	8.2	2.2	8.6	8.4	8.2	8.2	8.2	2.8
S13	4.8	6.2	5.6	7.2	6.6	5.4	5.4	6.2	5.6	5.8	6.6	5.4	6.2	6.6	5.6
S14	6.6	6.4	7.4	5.2	7.2	6.2	6.8	6.4	4.8	7.2	7.4	6.6	6.6	7.6	4.8
S15	2.8	3.2	2.2	2.6	2.4	2.8	2.4	2.6	8.2	2.4	1.8	2.2	2.6	3.2	8.8
S16	4.2	4.4	3.2	4.	5.2	3.2	4.2	4.8	8.4	3.4	3.	3.	4.2	4.4	8.2

Attributes	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15
				6							8	4			
S17	9.2	9.6	8.6	8.2	9.8	8.2	۹,۲	8.6	2.4	9.8	۸,۸	9.2	9.4	8.6	1.6
S18	4.4	5.6	5.6	6.2	6.2	4.8	4.4	5.2	6.4	5.2	5.4	4.4	5.8	5.6	6.6
S19	3.4	5.2	2.6	4.2	4.2	2.4	3.2	3.6	8.6	3.2	2.4	2.8	3.2	3.8	8.8
S20	9.6	8.2	8.8	9.4	8.2	8.8	8.8	9.6	3.8	8.2	8.4	8.6	8.8	8.2	3.2

Problem modeling: Regarding the experts' opinion in all membership functions, the lower bound was considered equal to the weekly demand of the mentioned item and the upper bound was considered as 500. Therefore, the membership functions for maximum and minimum goals are written in accordance with Eq.15 and Eq.16, respectively.

$$\mu_{z1}(X) = \begin{cases} 1 & z_1 \geq 500 \\ \dfrac{z_1(x) - 50}{450} & 50 \leq z_1(x) \leq 500 \\ 0 & z_1 \leq 50 \end{cases} \tag{7}$$

$$\mu_{z9}(X) = \begin{cases} 1 & z_9 \leq 50 \\ \dfrac{500 - z_9(x)}{450} & 50 \leq z_9(x) \leq 500 \\ 0 & z_9 \geq 500 \end{cases} \tag{8}$$

After determining the membership functions, the problem is formulated as follows.

$$\text{MAX } 0.122\,\lambda_1 + 0.082\,\lambda_2 + 0.089\,\lambda_3 + \ldots + 0.015\,\lambda_{13} + 0.044\,\lambda_{14} + 0.099\,\lambda_{15}$$

s.t.

$$((5.4\,X_1 + 3.6\,X_2 + 7.8\,X_3 + \ldots + 4.4\,X_{18} + 3.4\,X_{19} + 9.6\,X_{20} - 50)/450) \geq \lambda_1$$
$$((7.4\,X_1 + 5.2\,X_2 + 8.2\,X_3 + \ldots + 5.6\,X_{18} + 5.2\,X_{19} + 8.2\,X_{20} - 50)/450) \geq \lambda_2$$
$$((5.8\,X_1 + 4.4\,X_2 + 7.2\,X_3 + \ldots + 5.6\,X_{18} + 2.6\,X_{19} + 8.8\,X_{20} - 50)/450) \geq \lambda_3 \tag{9}$$
$$((6.4\,X_1 + 5.2\,X_2 + 7.6\,X_3 + \ldots + 6.2\,X_{18} + 4.2\,X_{19} + 9.4\,X_{20} - 50)/450) \geq \lambda_4$$
$$((7.6\,X_1 + 6.2\,X_2 + 8.2\,X_3 + \ldots + 6.2\,X_{18} + 4.2\,X_{19} + 8.2\,X_{20} - 50)/450) \geq \lambda_5$$
$$((6.6\,X_1 + 4.8\,X_2 + 8.4\,X_3 + \ldots + 4.8\,X_{18} + 2.4\,X_{19} + 8.8\,X_{20} - 50)/450) \geq \lambda_6$$
$$((5.4\,X_1 + 3.6\,X_2 + 7.2\,X_3 + \ldots + 4.4\,X_{18} + 3.2\,X_{19} + 8.8\,X_{20} - 50)/450) \geq \lambda_7$$
$$((6.8\,X_1 + 5.4\,X_2 + 7.4\,X_3 + \ldots + 5.2\,X_{18} + 3.6\,X_{19} + 9.6\,X_{20} - 50)/450) \geq \lambda_8$$
$$((500 - 2.4\,X_1 - 2.8\,X_2 - 3.8\,X_3 - \ldots - 8.2\,X_{18} - 9.2\,X_{19} - 9.2\,X_{20})/450) \geq \lambda_9$$
$$((6.6\,X_1 + 5.2\,X_2 + 7.6\,X_3 + \ldots + 5.2\,X_{18} + 3.2\,X_{19} + 8.2\,X_{20} - 50)/450) \geq \lambda_{10}$$
$$((7.4\,X_1 + 4.8\,X_2 + 8.2\,X_3 + \ldots + 5.4\,X_{18} + 2.4\,X_{19} + 8.4\,X_{20} - 50)/450) \geq \lambda_{11}$$
$$((5.8\,X_1 + 5.2\,X_2 + 7.4\,X3 + \ldots + 4.4\,X_{18} + 2.8\,X_{19} + 8.6\,X_{20} - 50)/450) \geq \lambda_{12}$$
$$((6.2\,X_1 + 4.2\,X_2 + 7.4\,X_3 + \ldots + 5.8\,X_{18} + 3.2\,X_{19} + 8.8\,X_{20} - 50)/450) \geq \lambda_{13}$$
$$((7.4\,X_1 + 5.4\,X_2 + 8.2\,X_3 + \ldots + 5.6\,X_{18} + 3.8\,X_{19} + 8.2\,X_{20} - 50)/450) \geq \lambda_{14}$$
$$((500 - 1.6\,X_1 - 2.2\,X_2 - 3.2\,X_3 - \ldots - 8.8\,X_{18} - 9.4\,X_{19} - 9.6\,X_{20})/450) \geq \lambda_{15}$$
$$X_{1,3,8,10,13,14,19,20} \leq 5 \quad \text{and} \quad X_{2,6,7,9,15,16,17,18} \leq 10 \quad \text{and} \quad X_{4,5,11,12} \leq 15$$
$$X_1 + X_2 + X_3 + \ldots + X_{18} + X_{19} + X_{20} = 50$$
$$X_i \geq 0 \quad i = 1, 2, 3, \ldots, 20$$

X_i is the decision variable and the order value assigned to the i-th supplier.

The objective function coefficients are the weights obtained from the F-ANP, which demonstrates the priority degree of each goal. Then, a constraint is considered for each goal given the goal membership function. Therefore, we have 15 goal constraints. In addition to the goal constraints, there are some constraints on suppliers' capacity and also demand.

After modeling the problem, it is solved and the value that should be provided by each supplier is determined. With regard to the results, the order of the selected suppliers is done at their maximum capacity and no order is provided by the other suppliers.

S5 = 15	S8 = 5	S12 = 15	S17 = 10	S20 = 5

5. Conclusion

Since suppliers are one of the main sources of vulnerability in supply chains, the evaluation of suppliers' resilience is one of the most important ways to improve resilience of the supply chain; hence, this study is aimed to identify and investigate the evaluation attributes of suppliers' resilience from the two aspects of importance and effectiveness for choosing the resilient supplier in high tech industries. According to the studies described in the literature review, the researches of suppliers' evaluation in a resilient supply chain can be categorized into two general classes: the first category contains the researches performed by the management approach [13,16,19]. These studies have focused on finding the single sources in resilient chains, and to this end, the attributes related to the suppliers' resilience have been extracted. They have evaluated the suppliers' resilience using the multi attributes decision making methods and introduced the superior supplier. In other side, there are some researches that evaluated the suppliers and allocating orders to them in multiple source-finding using the mathematical modeling [14,17,18]. The presented study presented a way to combine the two approaches in this area to have benefits of each approach.

In this regard, by extracting the comprehensive attributes of suppliers' resilience, the weakness of ignoring them by the researchers of the second approach and also the lack of integrity in attributes of first approach, are compensated. Results showed that some attributes including, human resource management, visibility, and financial strength are the most influential factors. In terms of importance, agility, adaptability, and vulnerability are also the most important factors. In this study, the efficiency of combining the applied methods (DEMATEL, analytic network process, goal programming, and fuzzy logic) is well illustrated with a case study.

6. Postscript

1. Analytic Network Process
2. Fuzzy Goal Programming

7. References

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