A hybrid approach based on ANP, ELECTRE and SIMANP metaheuristic method for outsourcing manufacturing procedures according to supply chain risks - Case study: A medical equipment manufacturer company in Iran

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CHRONICLE	ABSTRACT
	Nowadays enterprises should consider seeking to reduce the supply chain risks as a crucial part of their activities in order to improve their competitiveness in the international context. Choosing the suitable strategy in connection with assigning some parts of the production process to outside the organization is a complex multi-criteria decision making problem and it gets more complicated when supply chain risk factors as the factors to select the strategy as well as dependence and the close ties between these criteria also be considered. In this paper, after the identification of risks in the supply chain of a medical equipment manufacturer company, dependence and ties between criteria in line with choosing the best strategy among existing alternatives has been examined in the form of a combined ANP-ELECTRE method. This combined model has high performance to give a solution to the problem considered in this paper. Because of the complexity and time consuming nature of the AHP and ELECTRE, in this study a metaheuristic algorithm is developed called SIMANP that despite the simplicity of computing and high-speed, is good in the terms of precision and efficiency. The results of comparing SIMANP algorithm and the proposed ANP - ELECTRE method are presented at the end of the paper.

1. Introduction

Since 1980, many of organizations have referred their manufacturing operations out of their internal borders in order to reduce manufacturing costs and thus reduce the cost of the entire system (Schoenherr et al., 2008). In fact, Outsourcing is an increasingly significant topic pursued via corporations seeking enhanced efficiency (Azadi & Saen, 2011). Since parts and materials purchased from suppliers are accounted for a large part of production costs, therefore, supply chain cost management is as a key element in the management of total cost of the organization and increase profitability. In many countries, including China and India in 1980 and 1990, the production lines were transferred to South American countries such as Mexico (Schoenherr et al., 2008). These benefits include a significant

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reduction in production costs, cheap labor etc. However it can lead to a very complex supply network that creates a lot of risks. These risks include low quality products, increased transport costs, reduced reliability, disruption of supply chain, logistics problems, natural disasters and increased communication problems. Also nowadays, the fierce competition in global markets, the emergence of products with short life cycles and increasing customer expectations, have made commercial organizations to capitalize on their supply chain and its management. In addition, factors such as political issues, fluctuations in demand, technological change, financial instability and natural disasters increase uncertainty and risk in the supply chain which cause the formation of supply chain risk management (Vanany et al., 2009; Brindley, 2004). Risk management in the supply chain is through coordination and cooperation among the components of the supply chain in a way that ensures profitability and continuity of the supply chain (Tang, 2006).

The fact that these risks must be identified and examined initially by the organizations is very necessary and organizations must do efforts required to reduce the risks and increase the benefits of relocating any operations outside the internal borders in order to evaluate their outside alternatives for outsourcing some parts of manufacturing process and select the best ones. Since choosing a suitable outside alternative to do a part of manufacturing process is considered as a solution and an operational strategy among the other available solutions, being aware of the importance of making decisions about producing or buying from outside the borders is of the utmost importance. This is due to limited resources and lack of technology required in the production process. Nowadays supply chain risks are considered as an important criterion in supply chain management and since this paper seeks to evaluate and select the best solution among existing strategies related to manufacturing or purchasing from outside the organization, first the risks involved in the supply chain will be explained and then it is utilized to select the best alternative among existing ones in the following two-step process which is considered as the suggested method in this paper.

1. Identify existing risks in the supply chain by doing field survey in a medical equipment manufacturer company.

2. Combining ANP with ELECTRE method to remove less attractive alternatives and choose the best alternative from the ones available.

Finally, the SIMANP metaheuristic is developed method in order to provide a faster way to do the calculations with desired accuracy and the comparison of the results obtained is done through the AHP-ELECTRE proposed method.

The most important research questions include:

1. Which risks should be considered in the field of outsourcing decisions in the supply chain process?

2. What is an appropriate decision making structure to choose the best solution to transfer some parts of the production process outside the organization?

2. Literature review

Supply chain management

Supply chain management is a combination of art and science that improves ways of finding raw materials required for the production or service. Five main components of supply chain management include:

✓ Plan: plan is the strategic part of supply chain management.
✓ Source: Selecting suppliers that will deliver the goods and services needed for a product or service.
✓ Production: activities needed for the production, testing, packaging and finally preparation for delivery are done in this step.
✓ Delivery: This part is also known as logistics. Coordination of receiving customer orders, develop a network of warehouses and set up a system to pay bills, make up this section.
✓ Return: The problematic part of the supply chain. Building a network for receiving defective and returned products from customers and supporting customers who had problems with delivered product (Chopra, Sodhi, 2004).

2.1. Risk

Risk is an undesirable uncertainty, because it cannot be eliminated. So organizations are willing to tolerate that in return of getting some money. However they prefer to pay money to get rid of that. Also, organizations face with different risks in supply chain management (K.L.J.Litov, B.Yeung 2005). The following is a brief mention of the risks involved in the supply chain.

2.2. Risks of supply chain

Supply chain risks include cases that cause disruption and cut off the smooth flow of materials and information throughout the chain. This may include accidents related to transport operations, fires in warehouses, raw material shortages, low quality products , lack of efficiency and lack of trained personnel, flaws in the information system, etc. (Handfield, 2007). Risks involved in the supply chain can be divided into two general categories, internal risks and external risks. In practice, the internal risks and external ones in supply chain are not necessarily separated. As an example, it is possible that a financial problem in the organization is derived from the external environment caused by non-payment of financial statements by the purchaser. But after a while it will become an important issue of liquidity for corporate executives refer to as internal risk. There may be other such cases (Waters, 2007). Internal supply chain risks stems from operating activities within the organization, including various events, equipment reliability, failures in IT systems, human errors, etc. As well, a number of risks are more a result of the management decisions (Simchi-Levi, 2004). In general, the supply chain risks arise from the interaction between supply chain members that two of them are mentioned:

- Risks of suppliers: including reliability, availability of materials, procurement time, material delivery issues etc.
- Risks of consumers: include the variable demand, production based on order etc.

Among the main reasons causing this risk in the supply chain can be a lack of sufficient cooperation between supply chain members. In contrast to internal supply chain risks, external risks existing arising from interactions with the external environment of chain including external events, weather conditions, legislation, natural disasters, war, etc. The most important feature of this type of risk is that it's out of the control of management, so managers do not have the ability to change the risks (Waters, 2007). Their intrinsic and extensive properties of supply chains make them vulnerable to risks. So a small event in one part of the chain can cause different results for the rest of the chain. In general it can be said that external risks are beyond the control of management of the organization, while internal risks can be controlled (Waters, 2007).

2.3. *Risk management processes*

The first step in managing the risks of the supply chain is creating the risk strategy which is developed to reduce and balance operational risk of chain. Risk management in the supply chain is difficult and its causes can be various modes and forms of risks and differences in the planning horizon of managers and the organization (Rushton & Walker, 2007). Therefore, supply chain risk strategy should be integrated in all parts of the organization and yet comprehensible for all management levels of the organization. In addition, the organization must continuously examine changes in the environment that need correction and update in supply chain risk strategy. When an organization has a risk strategy, it is able to evaluate all risks in the chain and after the assessment risks can be managed according to supply chain risk management strategy (Swaminathan, 2007).

According to the items mentioned, it can be concluded that all risks in the supply chain are of particular importance and their management is a crucial issue accordingly. In addition, to the extent that outsourcing strategies in an organization grows, growth of potential risks is also not unexpected (Harland et al., 2003).

Risk assessment is one of the pillars of risk management and objectives to measure risk based on various factors such as the impact and likelihood of occurrence and as the results of this phase are more accurate, it can be said that the risk management process is carried out with a higher degree of certainty. Rating risks, is the key to this process and makes determining the priority of each risk against other risks available so decision makers can make plans about the resources available to deal with any risk (Ghosh & Jintanapakanont, 2004).

In Table 1, the most important researches in the field of supply chain risk and the way to deal with them are presented. According to Table 1, studies that include risk assessment have mainly used two indices (the impact) and (probability of occurrence) of risk in terms of probability-effect matrix. Some of the researchers have emphasized on unreliability of this process (Chapman & Ward, 2003). Including problems using probability - effect matrix is that a risk with low probability and important effect might be ignored. Also, the risks that are likely to have high probability and no significant effect are deemed equivalent with risks having low probability and significant impact (Pipattanapiwong, 2004).

Some other risk assessment methods such as FMEA are used in other researches that the value of risk is calculated by multiplying three indexes, intensity, discovery rate and the probability of risk occurrence. However, there are weaknesses and bugs mentioned in this method. However, in order to evaluate and rank the risks in the research that has been done in other areas apart from the supply chain, Other parameters such as (the organization's ability to respond to risk) (McDermott et al., 1996) (uncertainty in estimation) (Klein & Cork, 1998), probability and the possible impact on time and cost and quality of the projects have also been proposed in the ranking of risks (Baccarini & Archer, 2001).

Supplementary measures of manageability and risk occurrence proximity (Pertmaster Software, 2002) and socioeconomic effects and environmental impact has also been used (Xu & Liu, 2009). In cases where a substantial set of variables involved and there is the need to prioritize decision-making units based on their relative importance, utilization of various people ideas associated with the use of group decision making techniques and multiple attribute tools for ranking and making better decisions can be helpful (Pomerol & Romero, 2000).

Table 1
The most important researches in the field of supply chain risk

Study	Approach	Type of risk	technique	Studied field
Mangla et al., 2015	Field study	Green supply chain	fuzzy AHP	Risk management
Xia & Chen, 2011	Modelling	Aspects of the supply chain	ANP	Risk management
Venkatesh, 2015	Modelling	Retailers	Interpretation structural model	Risk analysis
Giannakis, et al., 2016	Conceptual	Sustainable supply chain	relational	Risk management
Guneri et al., 2015	Modelling	Relational	fuzzy AHP	Risk evaluation
Kim & Park, 2014	Field study	Financial	Risk reduction strategies	Risk evaluation
Badea et al., 2014	Modelling	Supply, production, distribution, services and information technology	AHP	Identification and risk assessment
Markmann et al., 2013	Conceptual	Wholesalers area	Probability- effect matrix, Delphi method	Identification and risk assessment
Dekker et al., 2013	Conceptual	Supply, production and sale	Delphi method	Identification and risk control
Wagner & Neshat, 2010	Modelling	Supply, demand	Graph theories	Risk evaluation
Tuncel & Alpan, 2010	Simulation	Suppliers, manufacturers and customers	FMEA	Identification and risk assessment
Sabio et al., 2010	Modelling	Financial	Mixed-integer linear programming	Risk management
Ravindran et al., 2010	Modelling	Supply and failure	Optimization and AHP	Risk management
Ellis et al., 2010	Field study	Supply	Interpretation structural model	Risk evaluation
Jia & Rutherford, 2010	Conceptual	Relational	modelling	Risk management
Tang & Musa, 2011	Literature review	-	-	-
Olson & Wu, 2010	Literature review	-	-	-
Thun & Hoenig, 2011	Field study	The structure of the chain	Probability- effect matrix	Identification and risk assessment
Tornow et al., 2009	Case study	Supply	Assessment of supply and demand	Identification and assessment
Oke & Gopalakrishnan, 2009	Case study	Supply and demand	Risk reduction strategies	Risk identification
Braunscheidel & Suresh, 2009	Conceptual	Failure risk	Study the effect of fragility	Risk management
Schoenherr, et al., 2008	Case study	Supply, demand, logistics, natural disasters, etc.	AHP	Risk evaluation
Tang & Tomlin, 2008	Modelling	Supply, demand and process	flexibility	Risk management
Kull & Closs, 2008	Simulation	Supply	Check the effect of the increase in inventories	Risk evaluation
Levary, 2008	Case study	Supply, natural disasters, related to human and transport	AHP	Risk management
Craighead et al., 2007	Conceptual	Risk of the failure	relational	Risk management
Ritchie & Brindley, 2007	Conceptual	Aspects of the supply chain	Integrating risk and performance	Risk management
Tang, 2006	Literature review	-	-	-
Faisal et al., 2006	Conceptual	Relational	Interpretation structural model	Risk management
Kleindorfer & Saad, 2005	Conceptual	Economic failures and terrorism	modelling	Risk management
Juttner, 2005	Conceptual	Supply, demand and environmental	modelling	Identification and risk assessment
Cavinato, 2004	Conceptual	-	-	Risk identification
Norrman & Jansson, 2004	Case study	-	-	Identification and risk assessment
Chopra & Sodhi, 2004	Conceptual	Failures, delays, forecasting,	-	Risk management
Zsidisin, 2003a	Case study	Supply	-	Identification and grouping
Zsidisin, 2003b	Conceptual	Supply	modelling	Risk identification
Ritchie & Brindley, 2000	Conceptual	-	-	Risk management, small and large organizations
Applequist et al., 2000	Modelling	Financial	Random contractual planning	Risk management

2.4.   Conceptual framework of the paper

The framework considered in this paper is a process combined of ANP (based on proposed algorithm in (Khademi, et al., 2012) and ELECTRE multi-criteria decision making methods. The reasons of selecting combined ELECTRE-ANP method is as follows:

1. ANP weight calculation method is more accurate compared to direct method and it is possible to determine the compatibility between the given weights. Using this method also measures the relationship between the criteria involved in weight calculation.

2. Due to the large number of criteria and also the probability to increase (risk factors) depending on the industry, working with analytic network process (ANP) will increase paired comparisons leading to lower accuracy in calculations. So after weight calculation of criteria using ANP, ELECTRE method is used to detect and remove the less attractive alternatives and select more effective method because in this method all the alternatives are evaluated using non-ranking calculations and ineffective alternatives are eliminated doing so.

3. Since the identified risk factors in this paper are considered as the selection criteria, the alternatives having the least risk will be selected compared to others. So the ELECTRE method is utilized to select the best method.

3. Research methodology

This paper is practical-developmental in terms of the objective and it is descriptive- analytical in terms of data gathering and analysis. Risks of the supply chain are used as evaluation criteria and selecting the best strategy of the company in this paper in order to outsource some parts of the manufacturing process so that the company is able to improve its manufacturing process. For this purpose, two important decisions making methods are utilized and the evaluation process of the alternatives are briefly explained:

Step 1: The objectives determination and the criteria assessment: at this stage, the criteria evaluation is performed toward to the objective and the importance of the criteria (W_i) is determined using the geometric mean method.

Step 2: Showing the relationship between the criteria: the relationship between the criteria and their dependence to each other is shown in the matrix form of $B_{N \times N} = \begin{bmatrix} b_{11} & \cdots & b_{1N} \\ \vdots & \ddots & \vdots \\ b_{N1} & \cdots & b_{NN} \end{bmatrix}$ in this step. Then it is changed to a matrix with no scale using percentage method and it is multiplied to the weights of criteria (W_i) to obtain final weights (W_C).

Step 3: Creating decision making matrix of $D_{M \times N} = \begin{bmatrix} d_{11} & \cdots & d_{1N} \\ \vdots & \ddots & \vdots \\ d_{M1} & \cdots & d \end{bmatrix}$ with each row assigned to an alternative and each column assigned to a specific criterion and each component of d_{ij} shows the value of ith alternative compared to jth one. So the decision matrix consists of M alternative and N criteria.

Step 4: Normalizing the decision making matrix of D using soft Euclidean method.

Step 5: Calculation of weighted matrix with no scales using $V = W_c \times R$ relation.

Step 6: Specifying a coordinated and uncoordinated set for each pair of $I, K = 1,2, \ldots, m ; I \neq K$ alternatives. The set of existing index is divided into (S_{KI}) coordinated distinct subset and uncoordinated (D_{KI}) subset. The coordinated subset of $S_{KI} = \{j | r_{Kj} \geq r_{Ij}\}$ consists of A_k, A_I alternatives and will include all indexes that A_K is preferred to A_I for them (i.e. r_{ij} is assumed with increasing utility) and on the contrary, uncoordinated collection of series of $D_{KI} = \{j | r_{Kj} < r_{Ij}\} = J - S_{KI}$ is a set of indexes that for them r_{ij} is assumed with decreasing utility.

Step 7: Calculation of coordination and incoordination matrices: The possible value from coordination set of (S_{KI}) is measured using the existing weights of coordinated indexes in the set. It means that each element (a measure of coordination) from the coordination matrix of $I_{KI} = \sum_{C_j \in S_{KI}} W_{C_i}$ is equal with the sum of weights of (S_{KI}) indexes which also means that each element (a measure of coordination) from the coordination matrix of **I** is equal with the sum of weights of (W_C) indexes that forms (S_{KI}) set.

In order to calculate the coordination matrix, the incoordination index of $NI_{K,I} = \frac{\max_{j \in D_{KI}} |V_{Kj} - V_{Ij}|}{\max_{j \in J} |V_{Kj} - V_{Ij}|}$ is calculated using the elements of V matrix (weighted values) for uncoordinated set of D_{KI}.

Step 8: Determination of effective coordinated matrix and effective uncoordinated matrix: the values of I_{KI} from the coordination matrix must be measured towards a threshold value to better judge the preferred chance of A_k to A_I. The minimum threshold value of $\bar{I} = \sum_{K=1}^{m} \sum_{I=1}^{m} I_{KI} / m(m-1)$ can be calculated. A Boolean matrix of $F = \begin{cases} f_{KI} = 1 \xrightarrow{if} I_{KI} \geq \bar{I} \\ f_{KI} = 0 \xrightarrow{if} I_{KI} \leq \bar{I} \end{cases}$ (with elements of zero and one) is formed.

Then each unit element in **F** matrix (the effective coordinated matrix) represents an effective alternative which is dominant over the other. But in order to calculate the effective uncoordinated matrix, the elements of uncoordinated matrix of $\overline{NI} = \sum_{K=1}^{m} \sum_{I=1}^{m} NI_{KI} / m(m-1)$ must be measured toward a threshold value.. Then a Boolean matrix of $G = \begin{cases} g_{KI} = 1 \xrightarrow{if} NI_{KI} \leq \overline{NI} \\ g_{KI} = 1 \xrightarrow{if} NI_{KI} > \overline{NI} \end{cases}$ (known as uncoordinated effective matrix) is formed and unit elements in this matrix show the relations among the alternatives.

Step 9: Specification of the general and effective matrix and removing the less attractive alternatives: common elements of $h_{KI} = f_{KI} \cdot g_{KI}$ form a general H matrix from F and G matrices to make decisions in the following way:

The general H matrix represents the relative importance of alternatives which means that A_K is preferred to A_I both in terms of coordination and incoordination. But A_K may still be dominated by other alternatives. Therefore, A_K is an effective alternative using ELECTRE method if $\begin{cases} h_{KI} = 1 \xrightarrow{for\ at\ least\ one\ I} K \neq I \\ h_{KI} = 0 \xrightarrow{for\ all\ I} K \neq I \end{cases}$. The existence of these two conditions simultaneously may be rare. However effective alternatives can be realized easily using H matrix in a way that each column of H matrix having at least one unit element can be eliminated because that column is dominated by a row or some rows.

4. Case study

A company which manufactures medical equipment that seeks to select the most appropriate strategy to improve its product lines is considered as a case study in this paper. One of the key strategies of this company is outsourcing and making decisions about finding sources from outside the organization. The company faces four alternatives to optimize its production process which should select the best strategy according to the efficiency and effectiveness of each of the alternatives in increasing profitability and reducing probable risks. External suppliers play an important role in improving the manufacturing process of the company and a bulk of the components and parts used in the production of the final products (operating room vital signs monitors) is provided by the suppliers which creates competitive advantage for the company's products in domestic markets and abroad. The placement of production lines inside or outside the country is not the matter to be investigated in this paper, but the problem is that which geographical area outside the organization is suitable for these lines and how much of the entire production process must be done there. Finding the resources of parts and raw materials needed by the company is done by a supplier abroad but the company has decided to check other alternatives in order to reduce the costs and improve the quality and innovation in products as well as profitability. The suggested process in this paper helps the manufacturing organizations to have more discretion in

selecting external alternatives to outsource some parts of the production process. In continuation of the review and analysis of the options facing the company are paid. Studying and analysis of alternatives facing the company is presented below.

1. Procurement of parts and raw materials from Singapore, and final product assembly in Tehran: By selecting this option parts and raw materials are procured from a supplier in Singapore and then transferred to Tehran and the final assembly is done in the company. Selecting this alternative involves advantages for the company including increased control over the assembly process and improving the quality of products in accordance with considered standards of manufacturer.

2. Procurement of completed equipment from Malaysia: Finding the resources for parts and raw materials has been mainly done this way. It means that a large part of the various stages of the manufacturing process has been done in the company contracted in Malaysia and selecting this alternative means the continuation of the company's present situation. On the other hand, continue to the current trend does not mean that the right to participate in other options is limited. Selecting this alternative, completed equipment are transferred from Malaysia to the company in Tehran using air transportation and then the final product manufacturing process is performed.

3. Procurement of completed equipment from Germany: Selecting this alternative not only the supplier source is transferred to another country but also another continent and this change of source may make the supply chain more complicated. As an instance, transportation to company in destination is a combination of aviation, marine and motor transportation because the ordered equipment is not directly transferred to Iran because of political reasons. But first, it is transferred to one independent country from the Persian Gulf countries and then it is transferred to Iran with the help of intermediaries and this causes change in the supply chain.

4. Procurement of parts and raw materials from Germany and final assembly in Malaysia through investment and joint venture with a German company: This includes investment in medical equipment production Installation in Malaysia done through the investment of a German company. Selecting this alternative increases the complication of supply chain that in the meantime, increasing the number of elements in chain and delays of transportation can be mentioned. The benefits of this strategy include providing qualified raw materials from Germany and final assembly performed by cheap labor in Malaysia's and then the final product transportation to Tehran through airlines. It should be noted that with respect to the joint investment with German counterpart, both companies in proportion to the share of investment, will benefit the profits.

Supply chain risk assessment framework is shown in Figure 1. In this diagram, the risk factors are considered as the criteria for selecting the best alternative among four considered ones. Much research has been done to identify the causes of supply chain risks. But noteworthy in this study is taking into account the relationships and mutual influences of risk factors in supply chain as the selection criteria. Now the 17 risk factors identified in this study are explained. In Figure 1, the objectives of Level 1 include features related to product sourcing, partners and the environment that the two products and partners have been divided into a number of sub-objectives. In relation to the target product, two sub-objectives of quality and cost have been proposed that their related risk factors are as follows:

• The product quality (product failure rate): Suppliers must be able to meet the minimum standards of the final products to minimize the failure rate.
• Execution of systemic standard (ISO 13485): Represents the minimum level of acceptable quality for the production of medical equipment.
• Product cost: includes the price of products that the organization pays to its suppliers.

- Competitors cost: the assessment of the purchasing cost of the organization compared to competing companies. Or in other words, the cost that the rival organization pays to the supplier to buy a similar product.

In conjunction with partners objectives, two sub objectives of services and management capabilities are of the utmost importance that the identified risk factors related to these sub-objectives re as follows:

- Demand risk: measures the likelihood and extent of fluctuations in product demand.
- Commitment risk of suppliers: The precision and commitment of suppliers for fulfilling the company orders from various aspects such as evaluation of quantitative and qualitative levels.
- Logistics risks: include uncertainty regarding the organizational aspects of logistics such as scheduling routes, selecting the harbor and transportation, completion of administrative law and what, how, at what time should be transferred.
- On time delivery: assesses the precision of a supplier in relation to responsiveness and flexibility of the transportation.
- Completing orders risk: the possibility of completion of the ordered products in terms of quality and quantity at the designated time will be assessed.
- Supplier's risk: the risk of supplier's bankruptcy or leaving the relevant business is evaluated.
- Overseas risk: the probability of disorders in the management of the external relations is measured. For example, due to political and cultural factors or time and place barriers as well as ethnic and linguistic differences between the countries, management of external relations is difficult.
- Supplier management: the way to manage the resources of first place suppliers or immediate suppliers is evaluated. The first place suppliers must have the necessary reliability. Because it is possible that first place suppliers will not be able to complete orders for various reasons, including lack of access to first-class raw and acceptable enough materials. As a result, the suppliers of next places will provide orders of first place suppliers. So, how to manage suppliers is very important.

As it is shown in Fig.1,

- Choosing the wrong partner risk: represents the probability of selecting partners with the possibility of poor performance and lacking sufficient performance in relation to the business. In a way that the selected partner does not have the ability for providing appropriate services to the client or an inappropriate supplier is selected to purchase materials and equipment.
- Engineering and innovation: shows the capabilities of suppliers in product innovation and appropriate design.

As shown in Fig. 1, the third main objective of the three participant ones is the environmental characteristics that the related identified risk factors are as follows:

- ✓ Transportation risk: studies the possibility of problems in the transportation facilities that play an important role in the physical relocation of parts and equipment. These problems can include existing infrastructure in the host country, the capacity of harbors, cargo handling equipment, human resources and so on.
- ✓ Incidents and natural disasters: the occurrence probability of incidents that may disrupt the supply chain, such as floods, storms, etc. are examined.
- ✓ Board of directors' risk: including issues such as instability in political decisions, organizational strikes or cumbersome governmental rules that does not allow administrators to control the status properly.
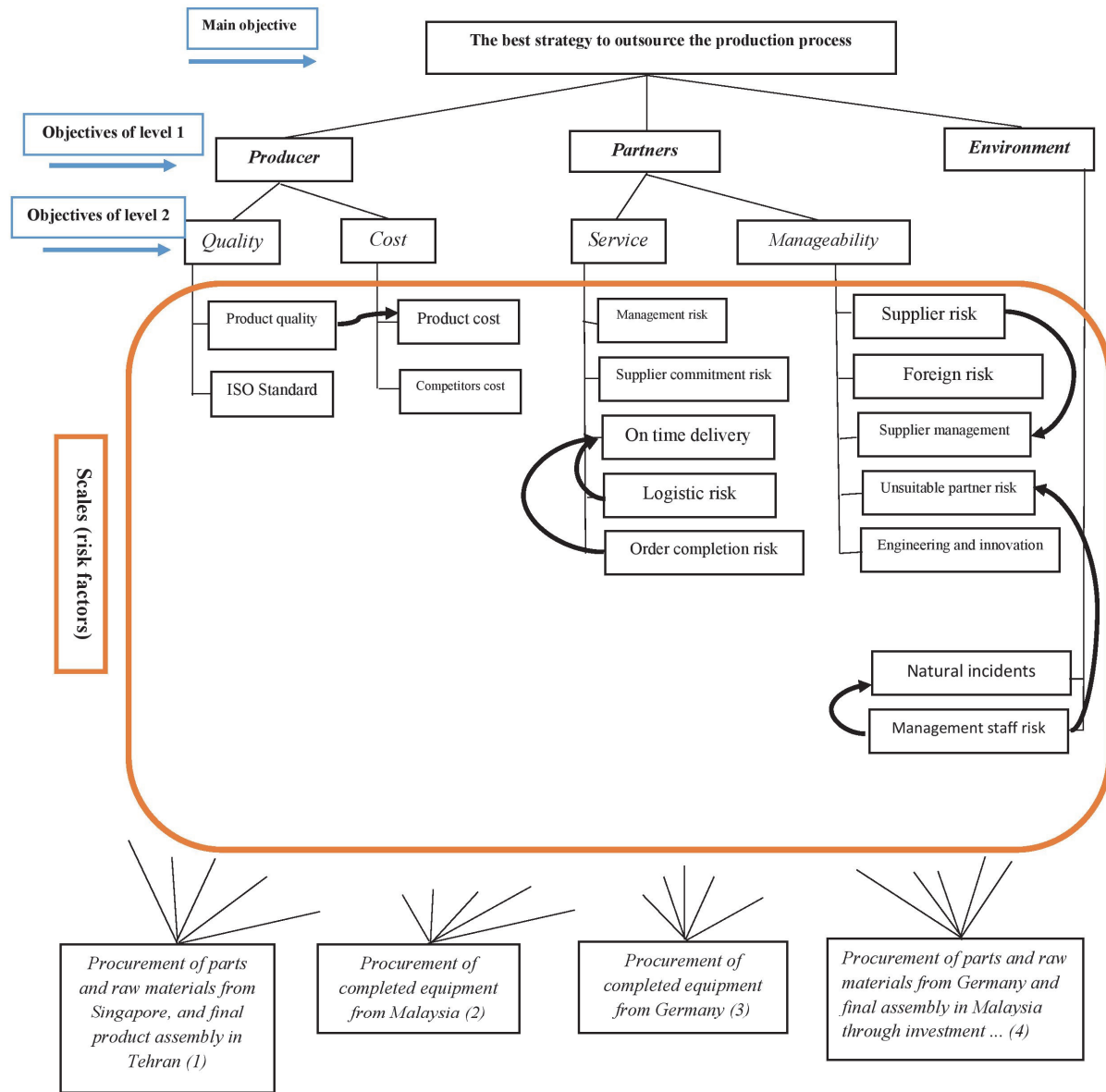
Fig. 1. The hierarchy of selecting for the best strategy the supply chain risk

As can be seen in Fig. 1, the influence of some standards and their interaction are shown. Then, using the proposed process, the alternatives considered by the company are assessed and prioritized. It should be noted that the oral judgments are used in doing comparisons in a way that if ith element is compared to jth element, it is said the importance of i *to* j is one of the following states that are changed into quantities from 1 to 9. These judgments are proposed by Saati(1980). The weights of factors in each

matrix are calculated and after making sure of the incompatibility rate of matrix in the range of acceptable less than 0.1, The fig. is used as the weights of factors compared in the matrix. After final calculations weights of criteria (W_i) toward the main objective are obtained according to the Table 2.

Table 2
The general weights of criteria (risk factors) toward the main objective, obtained from step 1

Risk factor	W_i	Risk factor	W_i
Product cost	0.256	Management staff risk	0.022
Product quality	0.246	Unsuitable partner choice risk	0.021
Order completion risk	0.065	Foreign risk	0.021
Transportation risk	0.063	Supplier risk	0.020
ISO 13485	0.062	Demand risk	0.010
Competitors cost	0.051	Supplier management	0.008
Supplier commitment risk	0.051	Natural incidents and disasters	0.008
On time delivery	0.051	Engineering and innovation	0.002
Logistic risk	0.043	The sum of weights	1.00

Considering that the total incompatibility rate is less than (0,1), so these paired comparisons are accepted. Now, according to step 2, the matrix of inter criteria relations (identified risk factors) is formed. Matrix numbers are based on the opinions of managers and experts in the purchase and supply of materials entered carefully and not based on judgments. After the formation of the matrix B it is normalized in percent and multiplied to the weight vector toward the objective (W_i) in order to obtain the final criteria (W_c) based on Table 3.

Table 3
Final weights of identified risk factors

Risk factor	W_c	Risk factor	W_c
Product cost	0.142	Management staff risk	0.012
Product quality	0.36	Unsuitable partner choice risk	0.021
Order completion risk	0.082	Foreign risk	0.025
Transportation risk	0.063	Supplier risk	0.02
ISO 13485	0.063	Demand risk	0.005
competitor cost	0.051	Supplier management	0.008
Supplier commitment risk	0.025	Natural incidents and disasters	0.008
On time delivery	0.06	Engineering and innovation	0.001
Logistic risk	0.052	The sum of weights	0.998

After the calculation of the final weights of the criteria (W_c), ELECTRE method is used in order to remove non-effective alternatives and choose the most effective option among 4 alternatives available. Therefore the decision matrix of D is formed for the 4 alternatives considered and 17 identified risk factor as presented in Table 4.

Table 4
The decision matrix of D for the 4 alternatives considered and 17 identified risk factor

	Product cost	Product quality	Order completion risk	ISO 13485	Competitors cost	Supplier commitment risk	On time delivery	Logistic risk	Management staff risk	Unsuitable partner choice risk	Foreign risk	Supplier risk	Demand risk	Supplier management	Natural incidents and disasters	Engineering and innovation	Transportation risk
(1)	0.04	0.03	0.09	0.06	0.02	0.02	0.01	0.06	0.05	0.07	0.03	0.01	0.07	0.01	0.04	0.03	0.07
(2)	0.02	0.02	0.02	0.01	0.05	0.08	0.03	0.02	0.01	0.06	0.06	0.03	0.07	0.03	0.01	0.05	0.03
(3)	0.01	0.05	0.03	0.05	0.08	0.02	0.08	0.01	0.03	0.07	0.05	0.02	0.02	0.01	0.02	0.01	0.01
(4)	0.02	0.03	0.06	0.03	0.01	0.08	0.02	0.08	0.02	0.05	0.02	0.01	0.01	0.02	0.03	0.06	0.02

It should be noted that the matrix of numbers represents the possibility of risk due to past experiences with regard to the selected alternative and as the risk occurrence probability related to an alternative is less, that alternative is considered as a priority by corporate managers of the company. The numbers entered in D decision matrix has been set based on previous purchases from suppliers and by the opinions of company experts. Matrix D is normalized according to steps 4 and 5 and then multiply it into the weights obtained for criteria from the (W_c) matrix in order to have the weighted matrix with no scales. After the formation of V weighted matrix with no scales, the coordination set of S_{KJ} and the incoordination set of D_{KJ} are determined.

$$I = \begin{bmatrix} - & 0.776 & 0.77 & 0.84 \\ 0.234 & - & 0.713 & 0.708 \\ 0.226 & 0.279 & - & 0.205 \\ 0.156 & 0.288 & 0.791 & - \end{bmatrix} \qquad NI = \begin{bmatrix} - & 0.318 & 0.01 & 0.244 \\ 1 & - & 0.055 & 0.782 \\ 1 & 1 & - & 0.205 \\ 1 & 1 & 0.048 & - \end{bmatrix}$$

The determination of coordinated effective matrix and effective matrix are based on $I = \sum_{K=1}^{4}\sum_{I=1}^{4} I_{KJ}/12 = \frac{5.976}{12} = 0.498$ and $NI = \sum_{K=1}^{4}\sum_{I=1}^{4} NI_{KJ}/12 = \frac{7.457}{12} = 0.621$. The general matrix of $H = \begin{bmatrix} - & 1 & 1 & 1 \\ 0 & - & 1 & 0 \\ 0 & 0 & - & 0 \\ 0 & 0 & 1 & - \end{bmatrix}$ indicatesType equation here. the relative priority of alternatives. Each column of this matrix having at least one unit element can be eliminated because that column is dominated by a row or some rows. So the first alternative is the most effective one and then the second and forth alternatives are considered as less attractive alternatives and finally the third alternative is the least attractive one.

5. The SIMANP metaheuristic method:

SIMP method involves the following steps; the first five steps are similar to Sa'ati's ANP method:

 1. *Creating the model and changing the problem / issue to a network structure*

Model creation includes the following steps:

- Problem and objective definition
- Determination of criteria and decision making alternatives.
- Drawing a network structure in which the nodes are considered as clusters.
- Identifying the interdependencies of elements in a cluster with the arrow on the edges of the cluster and interdependencies with rings within the clusters.

 a. Compare binary matrix formation and determination of the priority vectors

The paired comparisons are performed based on subjective analysis of the elements of a cluster in terms of related elements that are from the same cluster or other clusters and these comparisons are iterated for all clusters. These comparisons will initially be in the form of qualitative Likert statements and then can be quantified as a numerical scale of 1 to 9. The pairwise comparison matrices are formed then and relative weights of elements are measured such as the AHP method.

 b. Calculating the size of the inconsistency of pairwise comparison matrices

In this step, the error due to the inconsistency of pairwise comparison matrix is calculated. This error is calculated such as the AHP method.

The value of inconsistency criteria is calculated using $C.R = \frac{C.I}{R.I}$. Individual judgments are done through $C.I = \frac{\lambda_{max}-n}{n-1}$ and group judgments are done using $C.I = \frac{\lambda_{max}}{n}$. If matrix inconsistency index is smaller than (0.1), the judgment is acceptable; otherwise it should be revised.

c. Imbalanced super matrix formation

The alternatives, criteria and sub-criteria are all brought in rows and columns in super matrix structure and relative weights obtained in pairwise comparison matrices are placed in this matrix and also if an element is related to itself the value of 1 is assigned to the imbalanced super matrix. The figure below shows the general structure of the super matrix. Jth element is of ith cluster and W_{ik} is the block matrix that represents the weight of the vector affected by the ith component of the cluster associated with the kth cluster.

If association between clusters exists, the pairwise comparison matrix of clusters is formed and the relative weight of clusters are obtained and entered into a matrix called the AHP matrix such as the cluster method.

d. The formation of weighted super matrix

At this stage the weighted super matrix is obtained by multiplying the non-weighted matrix values into cluster matrix and normalization of each column of non-weighted super matrix.

The differentiation of SIMANP method is clear in the later stages including:

e. The calculation of weighed super matrix

The elements in problem (e_{ij}) are divided into two categories of sub criteria and alternatives. So if the number of sub criteria is equal to n ($C_1, C_2, ..., C_n$) and the number of alternatives are equal to m ($A_1, A_2, ..., A_m$), the weighted super matrix is as follows:

Figure2, the weighted supper matrix

$$
\begin{array}{cc}
 & \begin{array}{cc} C & A \end{array} \\
\begin{array}{c} C \\ A \end{array} &
\begin{bmatrix} W_{cc} & W_{cA} \\ W_{Ac} & W_{AA} \end{bmatrix}
\end{array}
$$

The weighed super matrix is composed of 4 following matrices:

1. $[W_{cc}]$: The matrix of relative weights of sub criteria in terms of sub criteria.
2. $[W_{cA}]$: The matrix of relative weights of sub criteria in terms of alternatives.
3. $[W_{AC}]$: The matrix of relative weights of alternatives in terms of sub criteria.
4. $[W_{AA}]$: The matrix of relative weights of alternatives in terms of alternatives.

In this step the values of $u_l = \sum_j W_{C_l C_j} + \sum_j W_{C_l A}$ are obtained as below. Simply, $\bar{u} = \begin{bmatrix} u_1 \\ \vdots \\ u_n \end{bmatrix}$ is equal to the sum of relative weights of C_l criteria in terms of criteria and alternatives of weighted super matrix.

After u_l is obtained, $\bar{u}$ is formed and finally $\bar{u}' = \begin{bmatrix} u'_1 = \frac{u_1}{u_1+ ...+ u_n} \\ \vdots \\ u'_n = \frac{u_n}{u_1+ ...+ u_n} \end{bmatrix}$ is obtained by normalizing $\bar{u}$.

2. The calculation of $\bar{L}$

$\bar{L} = [W_{AC}] \times \bar{u}'$ Is obtained in this step.

3. **The calculation of S_l**

The values of $S_l = \sum_j W_{A_l A_j} + \sum_j W_{A_j A_l}$ are obtained from the related weight matrix of alternatives in terms of alternatives as follows:

$$[W_{AA}] = \begin{bmatrix} W_{A_1 A_1} & \cdots & W_{A_1 A_m} \\ \vdots & \ddots & \vdots \\ W_{mA_1} & \cdots & W_{A_m A_m} \end{bmatrix}$$

$W_{A_l A_j}$ the relative weight of A_l in terms of A_j.
$W_{A_j A_l}$ the relative weight of A_j in terms of A_l.

Then $\bar{S} = \begin{bmatrix} S_1 \\ \vdots \\ S_m \end{bmatrix}$ is formed.

4. **The calculation of $\bar{N}$**
$\bar{N}_{m\times 1} = \bar{L}_{m\times 1} + \bar{S}_{m\times 1}$ is obtained.

5. **The normalization of $\bar{N}$**
Now, normalizing $\bar{N}_{m\times 1}$ using percent method $\overline{N'}_{m\times 1}$ is obtained which is the final relative weight of alternatives.

To assess the results of SIMANP, responses received from two proposed ANP_ELECTRE and SIMANP algorithm are compared and the results are shown in Table 6.

Table 6
Comparing the results of ANP-ELECTRE and SIMANP algorithm

	$ANP - ELECTRE$	$SIMANP$	$GAP \times 10^{-4}$
The cost of product	0.142	0.147	143
The quality of the product	0.36	0.36	0
Order completion risk	0.082	0.09	889
ISO 13485	0.063	0.058	862
Competitors costs	0.062	0.062	0
Supplier commitment risk	0.051	0.045	1333
On time delivery	0.025	0.026	346
Logistics risk	0.06	0.06	0
Board of directors risk	0.052	0.052	0
Risk of choosing inappropriate partner	0.012	0.015	2000
External risk	0.021	0.03	3000
Supplier risk	0.025	0.03	1667
Demand risk	0.005	0.006	1667
Supplier management	0.005	0.006	1667
Incidents and natural disasters	0.008	0.008	0
Engineering and innovation	0.008	0.006	3333
Transportation risk	0.001	0.001	0

6. Conclusion

Nowadays a number of industrial organizations provide part of their requirements by external suppliers or parts of the production lines are assigned to the out of the organization. In this context, each of the alternatives considered by the organizations, have the advantages and disadvantages regarding the evaluation criteria. In this study the risk factors contained in the company's supply chain are considered

as criteria for selecting the most suitable alternatives to transfer part of the production process. Due to this, the existence of a flexible method for measuring the constraints of suppliers and requirements of organization is necessary to evaluate and decide on the most appropriate and most effective solution. According to calculations carried out in accordance with the process proposed in this paper and the available information about the possible risks of the company's supply chain, the most appropriate and most effective solution among the four available alternatives to transfer part of the production process outside the borders, is supplying parts and raw materials from Singapore, and do the final product assembly in Tehran. This alternative involves advantages for the manufacturer company including increased control over the assembly process and enhanced the quality of products in accordance with the manufacturer considered standards. The second strategy for the company is to select one of two alternatives of the second one or the fourth one. The second alternative is a continuation of the previous trend to by the competed equipment from Malaysia. With this option, all the equipment is transferred from Malaysia on a weekly basis with the use of air freight to participate in Tehran and then final product manufacturing process is performed. And selecting the third alternative means the procurement of parts and raw materials is done in Germany and final product assembly is performed in Malaysia through investment and joint venture with a German company (This includes investment in medical equipment production facility in Malaysia through a joint venture with a German company). The least attractive alternative is the third option, because it increases the probability of risks and on the other hand political reasons and economic sanctions of related industries, makes this alternative non effective. Also in order to allow faster calculations while obtaining optimal results, the expressed problem is solved by SIMANP meta-heuristic algorithm and the results were presented. According to the results of the comparison between the two proposed algorithms it can be expressed that using the ANP - ELECTER combined algorithm provides more appropriate and acceptable results. But involves higher computational complexity compared to meta-heuristic method introduced. While the use of meta-heuristic algorithm is very fast and does not require software computations. So when quick results are preferred to high accuracy, using this method is suggested. Because the study only examined the relationship between measures considering the obtained results it is suggested to the researchers to study the relationship between alternatives and criteria and their relations in addition to the study of the relation between criteria and provide more accurate results in future studies.

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