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A Decision Making Model for Outsourcing of Manufacturing Activities by ANP and DEMATEL Under Fuzzy Environment

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ABSTRACT

Decision making about outsourcing or insourcing of manufacturing activities is a Multiple Criteria Decision Making (MCDM) problem, which requires considering many quantitative and qualitative factors as evaluative criteria simultaneously. Therefore, a suitable MCDM method could be useful in this area, take into account the interactions between quantitative and qualitative criteria. The analytic network process (ANP) is a relatively new MCDM method which can deal with different kinds of interactions systematically. Moreover, the Decision Making Trial and Evaluation Laboratory (DEMATEL) method is able to convert the cause and effect relations between of the criteria into a visual structural model as well as handling the inner dependences within a set of criteria. However both ANP method and DEMATEL techniques in their original forms are incapable to capture the uncertainty during value judgment elicitation. To overcome this problem, here, a new and effective model is proposed based on combining fuzzy ANP and fuzzy DEMATEL for decision making about outsourcing or insourcing of manufacturing activities in uncertain conditions. Data from a case study is used to illustrate the usefulness and applicability of the proposed method.

1. Introduction

Nowadays, complexities in the business atmosphere, an increase in the competition between manufactures, shortage of resources, and lots of other factors have caused producing organizations to move toward making use of optimum processes and decisions in order to guarantee the organization's exuberant permanence. From the Industrial Revolution to early 1980s, manufacturer's strategy was based on establishing processes and requirements related to the production of all the products or ordered ones within the organization. This was relied on the available resources and workforce; however, in facing lots of difficulties, so many organizations have moved toward specialization of activities, the division of labor, and a smarter planning of the issues. In this way, by improving primary qualities, gaining competitive advantages is accessible. It is clear that specialization and consequently, limiting the domain of activities, will be possible in the case of some chores to be outsourced. In fact, outsourcing is handing over some of the primary or non-primary chores of the organization which are carried out based on decision making processes; therefore some of these results will be acquired using outsourcing and some others insourcing. This causes a decrease in the system's vertical integration rate. In general, outsourcing is used

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to decline production costs, access to a higher technology and skill, efficiently use of the available time and limited resources on the organization, prevention the activities being messy, and finally prevention of the organization's unrestrained development and the related expenses.

Probert [1] presented a strategic methodology for production or purchasing decisions which was based on a thorough analysis of all the different aspects of production technologies. McIvor et al [2] by emphasizing the establishment of a sharing relationship with the chosen supplier, tried to present a conceptual framework for production or purchase of strategic goods. One of the applications of this framework is for the organizations in which so much strategic attention should be paid to decision-making in production or purchase. Padilo and Dibey [3] for the first time looked at this issue using a multitude of criteria. They presented a methodology for analyzing decision-making in seven stages to evaluate the strategies of production or purchase.

This methodology contains a comparative model which follows four aims simultaneously: maximizing the strategic performance of competition, maximizing the managerial performance, minimizing the risk of finding resources, and maximizing the financial performance. In this model various methods like complex programming and AHP have been used. Lance Dell [4] presented a conceptual framework to efficiently manage the risk of outsourcing, emphasizing taking into account the competitive advantages of the organization. Comann and Ronan [5] presented a model what investigates the state at which demand is more than supply and the management must decide to produce which quantity of that product and buy what quantity from contractors. They showed outsourcing as an issue of linear programming based on financial and capacity-related parameters.

Vals-pierre and Clain-Hans [6] worked out a set of if-so laws considering the criteria of purchase or production decision-making which by using verbal utterances we can make appropriate strategic decisions. Aktan et al [7] developed a financial model for evaluating the value of outsourcing options. In fact, this model provides a comprehensive framework for evaluating the whole expected costs of outsourcing from a network of suppliers when the purchase is faced with unknown exchange rate. For this purpose, Monte Carlo simulation method has been used. Tills and Dreary [8] developed a model which supports decision-making related to purchase or production based on an investigation of the goods and investment's being strategic.

Mom and Wallaby [9] developed a systematic framework for strategic outsourcing. This framework, with the help of internal management tools and external marketing tools, links 6 basic levels of outsourcing to strategic programming of the organization and helps the reciprocal linkages between the functions of the process of outsourcing to be known. Humphreys et al [10] used sophisticated systems based on KBS to design the model for evaluation of decisions made about purchase or production. This model is comprised of 5 major levels: identifying and weighing performance-related criteria, analyzing technical abilities, comparing internal and external capacities, analyzing the capabilities of the supplying organization, and analyzing the whole cost of ownership. KBS has linked all these 5 stages. Water and Pate [11] proposed a model of outsourcing decision-making which has more strategic focus and has a structure which makes it possible to use a technique in order to decrease the complexity of the process.

A comprehensive study of the related articles on this issue shows that by the passing the time, researchers have reached this conclusion that costs is not sufficient in making decisions about outsourcing or insourcing and other criteria must also be taken into account. However, developing a comprehensive and systematic procedure for making decisions about insourcing or outsourcing can be very helpful in decreasing the risks related to this decision-making.

In this article proposing a new hybrid multi-criteria model for decision-making, we have attempted to make decisions about outsourcing and insourcing related to productive activities in the occasions when there is no absoluteness based on a variety of qualitative and quantitative criteria. This model which is based on the combination of ANP and DEMATEL methods in fuzzy environment can make clear the verbal evaluations of decision-makers and overcome one of the difficulties of ANP, which is surveying a large number of pairs for achieving the importance weights of those criteria having an internal link to each other.

The rest of this paper is organized as follows. In Section 2, the theoretical foundations of outsourcing, and in Section 3 the foundations of the theory of fuzzy systems are described. In Section 4, an ANP fuzzy method, and in Section 5 the fuzzy DEMATEL technique is introduced. Section 6, is devoted to the proposed MCDM model. In Section 7, the proposed model is used for insourcing-outsourcing decision making process for several real-world cases finally, in Section 8, the conclusions are discussed.

2. Outsourcing

In this section we will talk about theoretical foundations and generalities of the theory of outsourcing.

Outsourcing is the shorthand form of "using outside resources". We present the meaning of each component of it:

Outside, means creating value in the outside of the organization. In fact, outside considers the boundaries of the organization. The idea of the borderless organization is the incorporation of outside partners in order to establish and increase the value of the ultimate costumers.

From the point of resources, the organization is considered as a unique set of resources and knowledge. Without acquiring these resources from the environment, the organization is not able to survive and compete with other organizations. It is the supplying manager's duty to analyze the resourceful markets in order to acquire competitive advantages.

Only to be informed from the outside resources is not sufficient. They can be used in order to support the organization's position in the competitive environment. Supply chain management is a method which enables the organizations to make use of these resources. [12]

So many times, outsourcing is used as a synonym to decision-making for externalization. Terms like ' production or purchase', integration/disintegration of activities', all refer to outsourcing. [13]

2.2. Advantages of Outsourcing

The rapid growth of outsourcing shows that both governmental and private institutions expect to attain some profits by making use of outsourcing. For example, all organizations expect to economize in their expenses. It is impossible to mention all of the advantages of outsourcing, but some of these advantages are so common that are attainable in all organizations. [14]

The advantages attributed to outsourcing are summarized in table 1.

Tab. 1. The expected advantages of outsourcing

Reference number	The expected advantage
[15],[16],[17],[18],[19],[20],[21],[22]	Economizing costs
[19],[16]	Decrease in the costs of investment
[20],[11]	Injection of liquidity
[15]	Turning permanent costs to variable costs
[20],[16]	Quality improvement
[20]	Increasing speed
[15],[16],[19],[20],[21]	More flexibility
[13],[12]	Access to most modern technology and infrastructure
[21],[20],[19],[16]	Access to skills and aptitudes
[13],[20],[16]	Increasing operational activities
[15],[16],[17],[19],[20],[22]	Increase focus on the basic functions
[22],[20]	Handing over the problematic functions
[14]	Replicating the rivals
[14]	Decrease in political pressures
[22],[20],[16]	Freeing the resources
[20]	Better management and responding
[22],[20],[15]	Financial clarity
[22],[19]	Sharing risks

2.3. Disadvantages and Risks Attributed to Outsourcing

Studies show that about the advantages attributed to outsourcing have been exaggerated in part. However, it is accepted that all of the risks attributed to it are not identified [14]. Some of the risks are mentioned in table 2.

Tab. 2. Potential risks of outsourcing

Reference number	Potential risk
[19],[20[,[21],[22],[23]	Unattained economizing or secret costs
[20],[21],[22],[24]	Decrease in flexibility
[16],[24]	Poor contract or selection of a weak supplier
[18],[20],[22],[23],[24]	Loosing knowledge, information, skills, or difficulty in regaining the function
[15],[16],[19],[20],[21], [22],[24]	Losing control and meritocracy
[16],[18],[22],[23],[25]	Dependency to the supplier
[21],[22],[23],[24]	The supplier risk (poor performance or bad relations, opportunistic behavior, poor understanding of business, lack of access to better skills or technologies.
[21]	Loosing costumer, opportunities, or validity
[21],[20]	Uncertainty, change in the environment
[19],[20],[23],[24]	Low morale, consequences related to the staff
[15]	Opposing benefits
[18],[19],[23]	Security consequences

2.4. Different Degrees of Outsourcing

Studying the preceding articles, we can find that the outsourcing could be categorized from 2 different aspects:

1- Regarding outsourcing extent

2- Regarding the level of decision making

Regarding the extent, outsourcing is divided into two types naming partial outsourcing and full-scale outsourcing.

3. The Theory of Fuzzy Sets

In the real world, so many decisions include ambiguity in the definition of aims, limitations, and possible actions which are not defined clearly [26]. The roots of this ambiguity are immeasurable data, incomplete data, and inaccessible information [27]. To solve this problem, fuzzy sets theory was proposed by Zade [28] as a mathematical method to face ambiguity in decision-making. This theory is used where decision-making is facing unclear and equivocal human linguistic utterances. The decision-makers are tended to evaluate everything based on their own past experiences and knowledge and usually utter estimates using equivocal linguist utterances. In order to unify the experiences, beliefs, and ideas of the decision-makers, it is better to transform linguistic estimates into fuzzy numbers. So, decision-making in the real world has made it necessary to use fuzzy numbers [29]. Decision-making in the case of outsourcing also is not accepted from this principle.

4. Analytical Fuzzy Network Process (FANP)

The ANP is the general form of the AHP [30] [31] [32] [33]. The ANP was designed to overcome the problem of dependence and feedback amongst criteria [34].

ANP uses the even comparisons matrices for the rating and grading the priorities. The output numbers in these matrices are definite and in cases which the output numbers face ambiguity, we can use these matrices.

To solve this problem, Cheng and colleagues [35], have proposed a model that uses ANP in the fuzzy environment.

The difference between this model and the ordinary ANP model is extracting the importance weights from even comparison matrices, which is explained in the following section. Other steps of this model are the same as the ordinary ANP model, so we avoid repeating them.

Accepting that each number in the matrices shows the personal opinion of decision-makers, and is a vague concept, for the purpose of unifying the different opinions of the experts, fuzzy numbers are used in equations (1) to (4):

$$L_{ij}, M_{ij}, U_{ij} \in [1/9, 9] L_{ij} \leq M_{ij} \backslash \leq U_{ij} \tag{1}$$

$$\hat{u}_{ij} = (L_{ij}, M_{ij}, U_{ij}) \quad L_{ij} = \min(B_{ijk}) \tag{2}$$

$$M_{ij} \sqrt[n]{\prod_{k=1}^{n} B_{ijk}} \tag{3}$$

$$U_{ij} = max(B_{ijk}) \tag{4}$$

In which, B_{ijk} refers to the k^{th} expert's judgment about the relative importance of the two criteria C_i, C_j.In the following the fuzzy $\tilde{A}$ matrix of even comparisons is presented by equation (5):

$$\tilde{A} = [\tilde{a}_{ij}] = \begin{array}{c} \\ c_1 \\ c_2 \\ \vdots \\ c_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \frac{1}{\tilde{a}_{12}} & 1 & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{\tilde{a}_{1n}} & \frac{1}{\tilde{a}_{2n}} & \cdots & 1 \end{bmatrix} \end{array} \tag{5}$$

In which $\tilde{a}_{12}$ is the referent for a triangular fuzzy number which is used in determining the relative importance of C_1, C_2. Meanwhile, $[\tilde{a}_{ij}]$ refers to a matrix which has been produced by fuzzy numbers based on the equations (1) to (4).

There are several defuzzification methods. The one used here, is the method proposed by Leo and Wang [36]. As is shown in equations (6) and (7), this method clearly can make the fuzzy observations understood.

$$g_{\alpha,\beta}(\tilde{a}_{ij}) = [\beta . f_\alpha(L_{ij}) + (1-\beta). f_\alpha(U_{ij})] \quad 0 \leq \beta \leq 1, 0 \leq \alpha \leq 1 \tag{6}$$

In which $f_\alpha(L_{ij}) = (M_{ij} - L_{ij}).\alpha + L_{ij}$ refers to the minimum amount of $\tilde{a}_{ij}$ section-α, and $f_\alpha(U_{ij}) = U_{ij} - (U_{ij} - M_{ij}).\alpha$ refers to the maximum amount of $\tilde{a}_{ij}$ section- α.

$$g_{\alpha,\beta}(\tilde{a}_{ij}) = 1/g_{\alpha,\beta}(\tilde{a}_{ij}) \quad 0 \leq \beta \leq 1, 0 \leq \alpha \leq 1, i > j \tag{7}$$

Because of the capability of this method in clearly showing the priority tolerance (α) and risk tolerance (β) of the decision-makers, these people can feel and touch the risks they are faced in different situations.

Furthermore α can be considered as stable or unstable conditions. When $\alpha = 0$, the uncertainty domain is in its highest amount. Also, the decision-making environment becomes more stable as α increases, and simultaneously, decision-making variance decreases. Also, α can be a number between 0 and 1 and usually is a set consisting ten numbers of 0/1, 0/2… 1 for showing the uncertainty.

In addition, while $\alpha = 0$ refers to the maximum amount of U_{ij} and minimum amount of L_{ij} in triangular fuzzy numbers, and $\alpha = 1$ refers to the geometrical mean of M_{ij} in triangular fuzzy numbers, β is considered as the pessimism rate of the decision-maker. When $\beta = 0$, the decision-maker is more optimistic, so the experts' agreement is the maximum amount of the higher limit of the triangular fuzzy number. When $\beta = 1$, the decision-maker is pessimistic and the domain of numbers .Each person's even comparisons matrix is shown as follows on equation (8):

$$g_{\alpha,\beta}(\tilde{A}) = g_{\alpha,\beta}([\tilde{a}_{ij}]) = \begin{array}{c} \\ c_1 \\ c_2 \\ \vdots \\ c_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} 1 & g_{\alpha,\beta}(\tilde{a}_{12}) & \cdots & g_{\alpha,\beta}(\tilde{a}_{1n}) \\ \frac{1}{g_{\alpha,\beta}(\tilde{a}_{12})} & 1 & \cdots & g_{\alpha,\beta}(\tilde{a}_{2n}) \\ \vdots & \vdots & \vdots & \vdots \\ \frac{1}{g_{\alpha,\beta}(\tilde{a}_{1n})} & \frac{1}{g_{\alpha,\beta}(\tilde{a}_{2n})} & \cdots & 1 \end{bmatrix} \end{array} \tag{8}$$

λ_{max} Refers to the special amount of even comparisons of the matrix $g_{\alpha,\beta}(\tilde{A})$.

$[g_{\alpha,\beta}(\tilde{A}) - \lambda_{max} I]W = 0$ And $g_{\alpha,\beta}(\tilde{A})W = \lambda_{max} W$ in which W refers to the special vector of $g_{\alpha,\beta}(\tilde{A}), 0 \leq \beta \leq 1, 0 \leq \alpha \leq 1$.

5. DEMATEL Fuzzy Technique

The DEMATEL method uses digraphs to categorize the influencing factors into two groups: cause group and effect group. [37] These diagraphs show the dependency relations between elements in a system, in a way that the numbers on each graph shows the amount of effect of each element on the other elements. So, DEMATEL can turn the relations between the causative and affective elements into an understandable structural model of the system [38].

Considering that for using DEMATEL we need experts' opinions and these opinions often include unclear and equivocal linguistic expressions, for integrating and clearing them, it’s better to turn them into fuzzy numbers. To solve this problem, Lin and Wu [39], have presented a model that makes use of DEMATEL in the fuzzy environment. Following on, we explain the steps involved in DEMATEL:

First step: determine the ideal for decision-making and establish a committee for gathering the ideas.

Second step: determining the evaluation criteria and designing a fuzzy linguistic measure.

Because of confronting so many ambiguities in human evaluations, we ignore the measures used in the ordinary DEMATEL model and instead, we use the fuzzy linguistic comparative measure, proposed by Lee [39]. Different degrees of 'effect' are expressed using five words: very high, high, low, very low, without effect. The related triangular fuzzy numbers are shown in the table 3 and fig. 1:

Tab. 3. numeric amounts of linguistic expressions

Numeric amounts	Linguistic expressions
(0.75,1,1)	Very high effect (VH)
(0.5,0.75,1)	High amount (H)
(0.25,0.5,0.75)	Low amount (L)
(0,0.25,0.5)	Very low effect (VL)
(0,0,0.25)	No effect (NO)

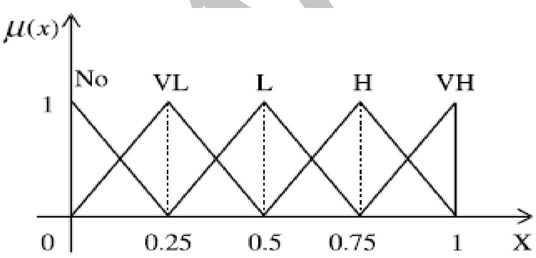

Fig. 1. Triangular fuzzy numbers for linguistic expressions

Third step: gather the evaluations made by decision-makers. To determine the relation between the criteria of $C = \{C_i | i = 1, 2, \dots, n\}$, a group of experts consisted of P expert, are being questioned in order to obtain a set of even comparisons according to linguistic expressions. So, P amount of fuzzy matrix $\tilde{Z}^{(1)}, \tilde{Z}^{(2)}, \dots, \tilde{Z}^{(P)}$ are produced in equation (9) for using the experts' opinions.

$$\tilde{Z}^{\langle k\rangle} = \begin{bmatrix} 0 & \tilde{z}_{12}^{\langle k\rangle} & \cdots & \tilde{z}_{1n}^{\langle k\rangle} \\ \tilde{z}_{21}^{\langle k\rangle} & 0 & \cdots & \tilde{z}_{2n}^{\langle k\rangle} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n1}^{\langle k\rangle} & z_{n2}^{\langle k\rangle} & \cdots & 0 \end{bmatrix}, k = 1, 2, \dots, p \tag{9}$$

In which $\tilde{z}_{ij}^{(k)} = \left(l_{ij}^{(k)}, m_{ij}^{(k)}, u_{ij}^{(k)}\right)$. The initial direct-relation fuzzy matrix is called the k^{th} expert.

Fourth step: obtaining the normal direct-relation fuzzy matrix. Suppose that $\tilde{a}_i^{(k)}$ is a triangular fuzzy numbers,

$$\tilde{a}_i^{(k)} = \sum_{j=1}^{n} \tilde{z}_{ij}^{(k)} = \left(\sum_{j=1}^{n} l_{ij}^{(k)}, \sum_{j=1}^{n} m_{ij}^{(k)}, \sum_{j=1}^{n} u_{ij}^{(k)}\right),$$
$$r^{(k)} = \max_{1 \le i \le n}\left(\sum_{j=1}^{n} u_{ij}^{(k)}\right)$$

Then to turn these criteria to comparable criteria, linear measure changing is used as a normalizing formula. The normalizing direct-relation fuzzy matrix of the k^{th} expert is shown in the equation (10), (11):

$$\tilde{X}^{\langle k\rangle} = \begin{bmatrix} \tilde{x}_{11}^{\langle k\rangle} & \tilde{x}_{12}^{\langle k\rangle} & \cdots & \tilde{x}_{1n}^{\langle k\rangle} \\ \tilde{x}_{21}^{\langle k\rangle} & x_{22}^{\langle k\rangle} & \cdots & \tilde{x}_{2n}^{\langle k\rangle} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1}^{\langle k\rangle} & \tilde{x}_{n2}^{\langle k\rangle} & \cdots & \tilde{x}_{nn}^{\langle k\rangle} \end{bmatrix} k = 1, 2, \dots, p \tag{10}$$

$$\tilde{x}_{ij}^{\langle k\rangle} = \frac{\tilde{z}_{ij}^{\langle k\rangle}}{r^{\langle k\rangle}} = \left(\frac{\ell_{ij}^{\langle k\rangle}}{r^{\langle k\rangle}}, \frac{m_{ij}^{\langle k\rangle}}{r^{\langle k\rangle}}, \frac{u_{ij}^{\langle k\rangle}}{r^{\langle k\rangle}}\right) \tag{11}$$

As the ordinary DEMATEL method, we suppose that there is at least one i which $\sum_{j=1}^{n} u_{ij}^{(k)} < r^{(k)}$. This supposition is calculated well, practically. Then, equations (12) to (14) are used to calculate the mean matrix of $\tilde{X}$, which is produced by $\tilde{X}^{(1)}, \tilde{X}^{(2)}, \dots, \tilde{X}^{(P)}$:

$$\tilde{X} = \frac{\left(\tilde{X}^{\langle 1\rangle} \oplus \tilde{X}^{\langle 2\rangle} \oplus \cdots \oplus \tilde{X}^{\langle p\rangle}\right)}{p} \tag{12}$$

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & x_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{n1} & \tilde{x}_{n2} & \cdots & \tilde{x}_{nn} \end{bmatrix} \tag{13}$$

$$\tilde{x}_{ij} = \frac{\sum_{k=1}^{p} \tilde{x}_{ij}^{\langle k\rangle}}{p} \tag{14}$$

In which, the fuzzy matrix $\tilde{X}$ is called the normal direct-relation fuzzy matrix. Here, we use the arithmetic average to integrate all of the data collected after the calculation of the normal direct-relation fuzzy matrix $(\tilde{X}^{(k)})$. This method is better than the integration of all the experts' data after calculating the initial direct-relation fuzzy matrix $(\tilde{Z}^{(k)})$.

Fifth step: execution and analyzing the structural model.

To measure the total-relation fuzzy matrix, first of all we must guarantee the convergence of $\lim_{w\to\infty} \tilde{X}^{w} = 0$. The elements of $\tilde{X}^{w}$ are also triangular fuzzy numbers.

Suppose that $\tilde{x}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, and consider the equation (15) from which the elements of $\tilde{X}$ are extracted:

$$X_\ell = \begin{bmatrix} 0 & \ell_{12} & \cdots & \ell_{1n} \\ \ell_{21} & 0 & \cdots & \ell_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \ell_{n1} & \ell_{n2} & \cdots & 0 \end{bmatrix}$$

$$X_m = \begin{bmatrix} 0 & m_{12} & \cdots & m_{1n} \\ m_{21} & 0 & \cdots & m_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ m_{n1} & m_{n2} & \cdots & 0 \end{bmatrix} \quad (15)$$

$$X_u = \begin{bmatrix} 0 & u_{12} & \cdots & u_{1n} \\ u_{21} & 0 & \cdots & u_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ u_{n1} & u_{n2} & \cdots & 0 \end{bmatrix}$$

According to the definite state, we define the total-relation fuzzy matrix with equation (16):

$$\tilde{T} = \lim_{W\to\infty} (\tilde{X} + \tilde{X}^2 + \cdots + \tilde{X}^W) = X \times (I - X)^{-1} \quad (16)$$

Theorem 1-5: suppose that:

in that case: $\tilde{t}_{ij} = (l''_{ij}, m''_{ij}, u''_{ij})$ in which $\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \tilde{t}_{2n} \\ \vdots & & \ddots & \vdots \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \tilde{t}_{nn} \end{bmatrix}$, $\mathrm{Matrix}[l''_{ij}] = X_l \times (I - X_l)^{-1}$, $\mathrm{Matrix}[m''_{ij}] = X_m \times (I - X_m)^{-1}$, $\mathrm{Matrix}[u''_{ij}] = X_u \times (I - X_u)^{-1}$

Now that the T matrix has been acquired, we use CFCSto defuzzification and obtaining total-relation fuzzy matrix.

The total-relation matrix of DEMATEL method can easily be replaced to ANP importance-weighing matrix of internal relations.

6. The Proposed Model for Outsourcing/Insourcing Decision-Making

Decision-making in issues related to insourcing and outsourcing of production activities, requires making use of a variety of qualitative and quantitative factors in a logical manner. So, decision-making in these issues is a multiple-criteria decision-making and for being solved, requires using systematic and highly dependable methods.

Most of the common MCDM methods are based on the presupposition of the independence of elements. But a criterion cannot be independent all the time. To solve the issue of facing with the elements reciprocal effects, Analytical Hierarchy Method was proposed by Saati as a rather new method of MCDM. ANP is able to consider various dependencies in a systematic way. This method has been successfully used in so many contexts. However, the function of ANP in dealing with dependencies is not faultless [41]. From another point of view, the DEMATEL method not only can turn the relations between cause and effect into a clear structural model, but also it can be used as a useful method in facing with the internal dependencies within a set of criteria. In fact, DEMATEL is able to present more valuable data to decision-makers than ANP method. [41, 42]

Considering that to use ANP and DEMATEL methods in decision making, it is necessary to make use of the experts' opinions and that these opinions are generally in the form of linguistic expressions, consisting of equivocal and vague concepts, both these methods are not able to make clear the linguistic evaluations conducted by the decision makers. In order to integrate and eliminate the vague points, it is good to turn the unclear linguistic expressions to fuzzy numbers and in fact these two methods be used in a fuzzy environment.

With respect to the mentioned advantages of ANP and DEMATEL, and the possibility of using them in the states of uncertainty, a new and effective method, based on the combination of ANP and DEMATEL methods is proposed in the fuzzy environment to help in decision making related to outsourcing and insourcing of production activities in the states of uncertainty.

The executive stages of this proposed model are based on the twelve steps of the common ANP method. The difference of this method with the common one is that where the internal elements of each bunch, or the secondary criteria of a controlling criterion, have reciprocal effects on each other, or technically speaking, have internal dependency, for determining the degree of this reciprocal effect and their dependency, instead of using the common method of even comparisons method in ANP, we use the results obtained by the total-relation matrix used in the fuzzy DEMATEL, introduced in part 5.

In other situations, to do even comparisons between effective indicators, even comparisons between each bunch, or between elements which effect each other in other bunches, the results obtained by the matrix of even comparisons in the fuzzy ANP method, introduced in part 4, is used instead of the common method of even comparisons used in the common ANP. The executive stages of this model are shown in fig.2 . In this way, not only the amount of calculations decreases, but also the linguistic analyses of decision makers are used in a more effective and convenient way.

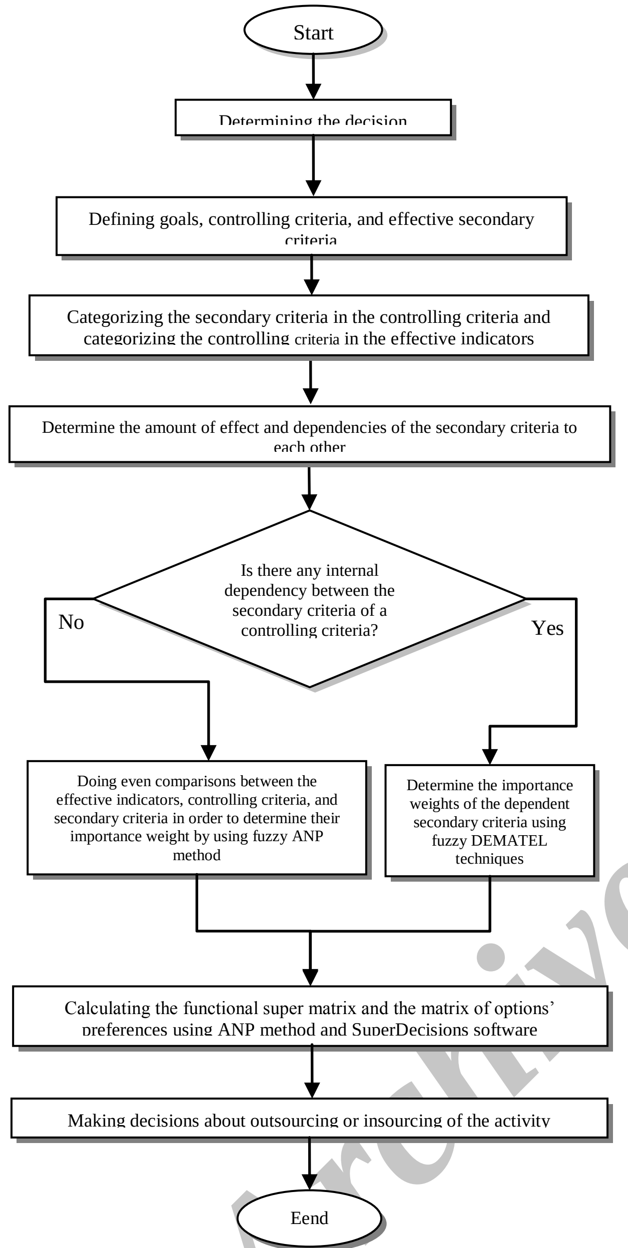

Fig. 2. The executive of proposal model of outsourcing or insourcing

7. Case Study

In order to show the applicability of the proposed model, we tried to execute this model on four products of a manufacturing corporation. These products include the set below the engine, the supporting set of back shield, the supporting set of front shield, and the set of glass lift in a kind of automobile. The rum under the engine, is the protecting tray under the engine and its' related parts that connects the engine to the automobile's chassis. This device decreases the tremors caused by the engine by using the engine handle and other elastic shock-absorbers. The function of the other devises is clear by their names. The corporation wants to know considering the supplier's and its own condition is it good to try to do outsourcing of each in the products or to try to produce them itself. For this goal, the researcher after designing the decision-making model, after having several sessions with the experts involved in these matters, tried to justify the problem and the proposed model and based on this, the model was proposed in the framework of BOCR of ANP method. The reason for using BOCR framework is that each producing corporation gains some profit, spends some costs, and is faced with some risks by way of outsourcing or insourcing in producing some product, this altogether must have convenient added value for the corporation.

For all of the mentioned products, we define a similar model, the ideal of which is to answer this question: is it better to outsource or insource in the production of this product? The options for this kind of decision-making are: outsourcing the production to one of A or B companies, insourcing the production, which means doing the job by the company itself, controlling criteria and their secondary criteria which have been used in the model, were determined by the decision-makers by using a questionnaire and were categorized in the effective indicators (BOCR) shown in table (4). Each of the secondary criteria mentioned above have an indicator for evaluation and measurement by using which, each option is being measured. These indicators are also determined by the decision-makers.

Tab. 4. Controlling criteria of decision-making networks and their secondary criteria

Secondary criteria	Controlling criteria	BOCR
1- Matching with the indicators 2-Mean time of replacement of the deported goods 3-Having quality management systems	quality	advantages
1-On-time delivery 2-Time of delivery	delivery	
1-Instrumental and capacity-related power 2- infrastructural power 3- expertise power and technical knowledge 4- Financial power	power	
1-focus on basic activities 2-Focus on the activities which are in accordance with the goals of the organization	staff	opportunities
1-costs 2-Transportation costs	Product cost	costs
1-Continuity in the production line 2-Quality control 3-Having the experience of expertise work	Work processes	risks
1-morale 2-permanence in the relations between management and staff	staff	
geographical distance	location	
Firm Firm B Insourcing		The whole networks

According to decision-makers' opinions, three controlling criteria of quality, delivery, and power which are defined for the benefits section of the model, added by the decision-making options, constitute a secondary network as shown in Fig. 3. For the 'opportunities', 'costs', and 'risks', similar secondary networks have been designed. After the evaluation made by companies A and B, and the insourcing using the above criteria's measurement indicators, and considering the formed relationships in decision-making models, we try to make even comparisons matrices of the importance of effective factors (BOCR), the controlling criteria, secondary criteria, and the even comparison matrices of those bunches which do not have any internal dependencies, and complete them with the help of decision-makers, using the results obtained from the evaluation of the measurement indicators.

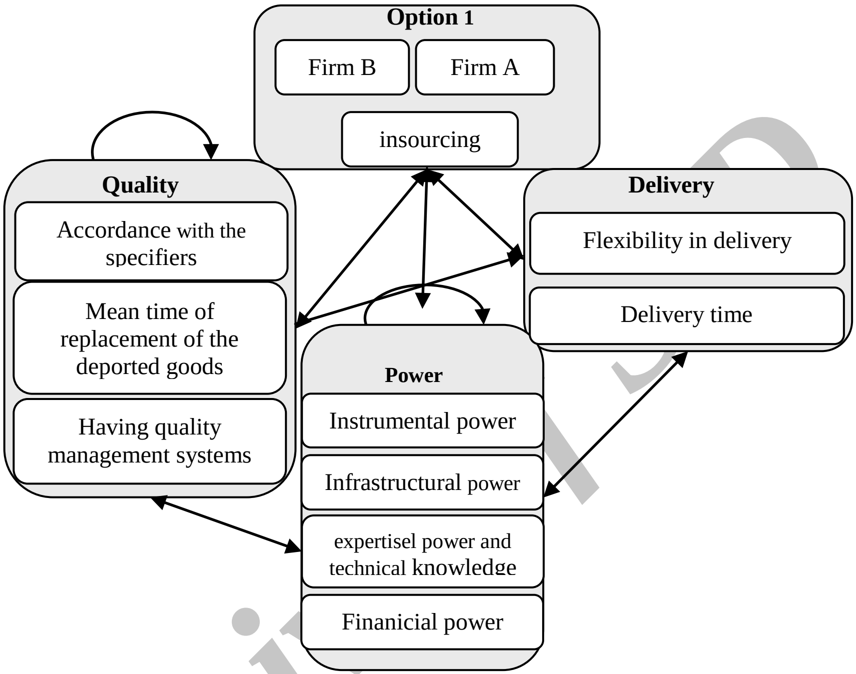

Fig. 3. Secondary network of the advantages

Then using the fuzzy ANP introduced in part 4, we measure the importance weights of each matrix and try to establish super matrices. In this super matrix, the place of the importance weight of those matrices which do have any internal dependencies is empty. With the help of the decision-makers opinions, we understood that in the benefits section, the two secondary controlling criteria of power and quality do have internal dependencies. In the opportunities section of the models also, the secondary criteria of the controlling criteria of the staff have internal dependencies, and in the risks section of the models, secondary criteria of the two controlling criteria, the staff and working processes have internal dependencies.

So, for measuring their matrix of importance weights, we only use a total-relation fuzzy DEMATEL technique, introduced in section 5, instead of several fuzzy ANP matrices of even comparisons. We can do other stages of the model by using SuperDecisions software. Because of the high quantity of the data and the conducted measurements, we only summarize the output of different super matrices and the final result of the model. In non-weight super matrices, those parts that are colored as grey show the importance weight measured by the total-relation matrix in fuzzy DEMATEL technique, and other parts show the importance weights measured by the ANP method. For example, in the case of the rum under the engine, we use the total-relation matrix to measure the controlling criteria of power and replace that with the importance weight measured by the ANP method. The result shown in tables (5) to (8).

Tab. 5. Linguistic analysis of the decision makers on the effects in the controlling criteria of power

	DD1	DD2	DD3	DD4
DD1	NNO	HH	VVL	LL
DD2	LL	NNO	VVL	HH
DD3	VVL	VVL	NNO	HH
DD4	VVL	VVH	LL	NNO

Tab. 6. The primary direct-relation matrix

	DD1	DD2	DD3	DD4
DD1	0.0000	0.6091	0.5333	0.5674
DD2	0.5333	0.0000	0.3671	0.7052
DD3	0.5674	0.3333	0.0000	0.3333
DD4	0.6000	0.6415	0.2638	0.0000

Tab. 7.The normal direct-relation matrix

	DD1	DD2	DD3	DD4
DD1	0.0000	0.0901	0.0792	0.0843
DD2	0.0792	0.0000	0.0546	0.1044
DD3	0.0843	0.0496	0.0000	0.0496
DD4	0.0892	0.0955	0.0393	0.0000

Tab. 8. Complete direct-relation matrix

	DD1	DD2	DD3	DD4
DD1	0.2630	0.4231	0.5465	0.1412
DD2	0.4556	0.2275	0.1384	0.2634
DD3	0.1413	0.1234	0.2324	0.1415
DD4	0.1413	0.2276	0.0845	0.4556

By primary preference we mean the first three numbers of the first column in the limiting super matrix. The normal preference is obtained by dividing each primary preference by the whole primary preferences. The ideal preference is also obtained by dividing each normal preference by the largest normal preference. It is evident from the above table that the insourcing of the project related to the rum under the engine, gains the largest profit for the company; also outsourcing the project to company B, gains the minimum amount of profits for the company. Because of the high quantity of data and calculations, we only present the final normal output of the four models.

Tab. 9. No weight super-matrix of advantages

		A1	A2	A3	B1	B2	B3	C1	C2	D1	D2	D3	D4
A1	Outsourcing	0.0000	0.0000	0.0000	0.7778	0.7778	0.8182	0.7778	0.7694	0.8182	0.7778	0.8182	0.8182
A2	Company(A)	0.0000	0.0000	0.0000	0.1111	0.1111	0.0909	0.1111	0.1778	0.0909	0.1111	0.0909	0.0909
A3	Company(B)	0.0000	0.0000	0.0000	0.1111	0.1111	0.0909	0.1111	0.0528	0.0909	0.1111	0.0909	0.0909
B1	Adaption with specification	0.8182	0.4737	0.7778	0.6370	0.1634	0.1634	0.0000	0.0000	0.1667	0.2500	0.6667	0.1220
B2	The average time to replace items returned	0.0909	0.4737	0.1111	0.2583	0.5396	0.5396	0.0000	0.0000	0.8333	0.7500	0.3333	0.2296
B3	Quality management systems	0.0909	0.0526	0.1111	0.1047	0.2970	0.2970	0.0000	0.0000	0.0000	0.0000	0.0000	0.6483
C1	Flexibility in delivery	0.8750	0.8333	0.8750	0.0000	0.2500	0.8333	0.0000	0.0000	0.1667	0.7500	0.6667	0.7500
C2	Delivery time	0.1250	0.1667	0.1250	1.000	0.7500	0.1667	0.0000	0.0000	0.8333	0.2500	0.3333	0.2500
D1	Power equipment and capacity	0.2111	0.6829	0.0700	0.0000	0.0000	0.0000	0.0000	0.0000	0.2630	0.4231	0.5465	0.1412
D2	Power infrastructure	0.6162	0.1762	0.0700	0.0000	0.0000	0.0000	0.0000	0.0000	0.4556	0.2275	0.1384	0.2634
D3	Professional and technical knowledge can	0.1391	0.0454	0.5384	0.0000	0.0000	0.0000	0.0000	0.0000	0.1413	0.1234	0.2324	0.1412
D4	Power financial	0.0336	0.0954	0.3215	1.0000	1.0000	1.0000	1.0000	1.0000	0.1413	0.2276	0.0845	0.4556

Tab. 10. Weight super-matrix of advantages

		A1	A2	A3	B1	B2	B3	C1	C2	D1	D2	D3	D4
A1	Outsourcing	0.0000	0.0000	0.0000	0.1944	0.3889	0.2045	0.3889	0.3847	0.2045	0.1944	0.2045	0.2045
A2	Company(A)	0.0000	0.0000	0.0000	0.0278	0.0556	0.0277	0.0556	0.0889	0.0227	0.0278	0.0227	0.0227
A3	Company(B)	0.0000	0.0000	0.0000	0.0278	0.0556	0.0227	0.0556	0.0264	0.0227	0.0278	0.0277	0.0227
B1	Adaption with specification	0.1564	0.0906	0.1487	0.1528	0.0392	0.0392	0.0000	0.0000	0.0417	0.0625	0.1667	0.0305
B2	The average time to replace items returned	0.0174	0.0906	0.0212	0.02620	0.1295	0.1295	0.0000	0.0000	0.2083	0.1875	0.0833	0.0574
B3	Quality management systems	0.0174	0.0101	0.0212	0.251	0.0712	0.0712	0.0000	0.0000	0.0000	0.0000	0.0000	0.1621
C1	Flexibility in delivery	0.0420	0.0400	0.0420	0.0000	0.1250	0.2083	0.0000	0.0000	0.0417	0.1875	0.1667	0.1875
C2	Delivery time	0.0060	0.0800	0.0060	0.2500	0.3750	0.0417	0.0000	0.0000	0.2083	0.0625	0.0833	0.0625
D1	Power equipment and capacity	0.1606	0.5195	0.0533	0.0000	0.0000	0.0000	0.0000	0.0000	0.1324	0.2125	0.2731	0.0701
D2	Power infrastructure	0.4688	0.1341	0.5333	0.0000	0.0000	0.0000	0.0000	0.0000	0.2287	0.1136	0.0694	01324
D3	Professional and technical knowledge can	0.1059	0.0346	0.4096	0.0000	0.0000	0.0000	0.0000	0.0000	0.0701	0.0613	0.1162	0.0701
D4	Power financial	0.0255	0.0726	0.2446	0.2500	0.2500	0.2500	0.5000	0.5000	0.0701	0.1142	0.0423	0.2287

Tab. 11. Functional super matrix of advantages

		A1	A2	A3	B1	B2	B3	C1	C2	D1	D2	D3	D4
A1	Outsourcing	0.1942	0.1942	0.1942	0.1942	0.1942	0.1942	0.1942	0.1942	0.1942	0.1942	0.1942	0.1942
A2	Company(A)	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.0285	0.2285	0.0285	0.0285	0.0285	0.0285
A3	Company(B)	0.0233	0.0233	0.0233	0.0233	0.0233	0.233	0.0233	0.0233	0.0233	0.0233	0.0233	0.0233
B1	Adaption with specification	0.0891	0.0891	0.0891	0.0891	0.0891	0.0891	0.0891	0.0891	0.0891	0.0891	0.0891	0.0891
B2	The average time to replace items returned	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578	0.0578
B3	Quality management systems	0.0312	0.0312	0.0312	0.0312	0.0312	0.0312	0.0312	0.0312	0.0312	0.0312	0.0312	0.0312
C1	Flexibility in delivery	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884	0.0884
C2	Delivery time	0.0835	0.835	0.0835	0.0835	0.0835	0.0835	0.0835	0.0835	0.0835	0.0835	0.0835	0.0835
D1	Power equipment and capacity	0.0709	0.0709	0.709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709	0.0709
D2	Power infrastructure	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139	0.1139
D3	Professional and technical knowledge can	0.0524	0.0524	0.0524	0.0524	0.0524	0.0524	0.0524	0.0524	0.0524	0.0524	0.0524	0.0524
D4	Power financial	0.1670	0.1670	0.1670	0.1670	0.1670	0.1670	0.1670	0.1670	0.1670	0.1670	0.1670	0.1670

Tab. 12. Options priorities with reference to the indicators of advantages

Options	Ideal Priority	Normal Priority	Initial Priority
In sourcing	1.0000	0.7720	0.1879
Company(A)	0.1059	0.0817	0.0199
Company(B)	0.1895	0.1463	0.0356

Tab. 13. The final normal priorities of options

Outsourcing		Insourcing	Product's name
Firm B	Firm A		
0.1579	0.0759	0.7662	Rum under the engine
0.2969	0.6175	0.0856	Supporter of the back shield
0.5286	0.3364	0.1350	Supporter of the front shield
0.1220	0.2297	0.6483	Left and right glass elevators

The above table takes into account the BOCR indicators simultaneously and determines the desirability of each option. The numbers within the table have been obtained using $bB+oO-cC-rR$ formula. The small letters are the ideal preferences for the options in the domains of profits, opportunities, costs, and risks. Capital letters, on the other hand, show the preferences of the effective indicators in the domains of profits, opportunities, costs, and risks for all models. Based on this we can conclude that in the case of the rum below the engine, the best option is insourcing its production. Also, it is better to outsource the production of the supportive set of the back shield to company A. outsourcing of the production of the supportive set of front shield is offered to company B, and the best option for producing glass escalators of right and left, is insourcing them.

8. Conclusion

As it was evident, the majority of the past decision-making models of insourcing and outsourcing has not considered this issue comprehensively and in a multidimensional way, and has only tried to solve the problem using a few qualitative or quantitative criteria. From another point of view, few models have been proposed related to decision-making in the case of determining insourcing of the production activities. Also, no method was found to be applicable in the fuzzy environment.

So, in this research, by presenting a new eclectic multi-criteria model of decision-making, we tried to make decisions about insourcing and outsourcing of production in cases of uncertainty based on various qualitative and quantitative criteria. In fact, this model can answer two questions simultaneously: the first question is that which activities should be insourced or outsourced? And the second is that to whom it should be handed over?

From a structural point of view, this model, which is based on the combination of ANP and DEMATEL in the fuzzy environment, in addition to making clear the vague points and uncertainties of the linguistics expressions of the decision-makers, solves one of problems of ANP method which is studying a large number of even comparisons to obtain the importance weights of those criteria which have internal dependencies.

Also, this model can calculate the amount of profits, opportunities, risks, and costs related to outsourcing and insourcing of the production activity, and make the decision-making process easier.

Considering the comprehensiveness of the criteria in this model, it can be used in the case of insourcing or outsourcing of every kind of product and also various decision-making options can be entered to the model according to the situations and priorities of the companies. In the future researches, work can be done on a model which answers this question: if the score of more than one company was positive, according to different criteria like capacity, number of personnel, and costs, to what extent each of the companies can take part in the project.

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