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# Ranking of manufacturers of mechanical parts based on a fuzzy multi-criteria decision making method: A case study in Iran National Steel Industrial Group

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## Abstract

Considering multiple criteria in evaluating manufacturers, high number of parts, orders and manufacturers for supplying parts of machinery and equipment, selecting the right manufacturer is a serious problem in steel rolling and production factories. The use of Multi-Criteria and methods in decision-making plays an important role in the selection speed and accuracy. Because of multiple criteria in evaluating manufacturers, selecting a limited and effective number of manufacturers seems difficult, so this study aimed to rank potential suppliers in order to identify the best supplier. Decisions in the outsourcing of mechanical parts are made based on multi-criteria methods and grouped decisions. So, this article proposes a method based on the grouped fuzzy decision-making approach in order to evaluate and rank the most suitable suppliers for outsourcing activities in Iran National Steel Industrial Group. Using the proposed method, experts presented their opinions in linguistic words, a range of numbers, deterministic or fuzzy numbers. Then each supplier was ranked based on the model criteria. On this basis, the most effective criteria in selecting companies were also identified.

**Keywords**: Ranking of fuzzy numbers, Decision making, Outsourcing, Manufacturers of Mechanical Parts

## Introduction

With the increased use of mechanization in industries, organizations' strategic policy-makers more and more are interested in parts supply to support machinery and installations in order to avoid production process interruptions. One such industry is the steel industry. Since the steel industry isa continuous production industry and these industries are the most dependent on machinery, parts supply is necessary for the maintenance of this equipment not only for cost reduction, product quality, organizational agility, and the value chain, but also it is a key factor in organizational development. Moreover, it will have significant and vital impactson other industriessuch as automobile industry, construction projects, home(electric) appliances, construction industry, etc. Partssupply management is necessary not only within the steel industry andits subset industriesbut also it has a major impact on other industries and on a larger scale on the country's economy. Therefore, parts supply management is a very important decision to support machinery and installations of the steel industry.

With the increase of purchasing and procurement activities, purchasing decisions have become more important and since today's organizations have become more dependent on suppliers, direct and indirect consequences of poor decisions in this area can cause irreparable damages to the organization. In such circumstances,supply strategies can play a key role in the efficiency and effectiveness of the organization and have a direct impact on reducing costs, profitability and flexibility of the organization. In fact, selecting the right set of suppliers is crucial to the success of a company, and in recent years,the emphasis has been on increasingthe efficiency and effectiveness of supplier selection systems so that decisions in this area has been considered the focal point of deci-

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sion makers as a strategic factor in the development and survival of organizations. The key and perhaps the most important purchase process is a function of effective supplier selection. The supplier selection process aims to reduce risk and increase total value to the buyer which includes considering a range of strategies and variablesso that the organizations'goal in the supplier selection and evaluation can be considered the process of finding the suppliers being able to provide the buyer with the right quality products and/or services at the right price, at the right quantities and at the right time (Khaled *et al.*, 2011).

In recent years, with the development of Iranian industries,thesupportmanagement of these industries has given special attention. One of these industries is the steel industry in the country so that statistical estimates in 2002 show that Iran ranked 22 in the world steel production ranking with a production of 7.3 million tons. In 2010, by producing more than 12 million tons of steel and an increase of 10 percent compared to 2009, Iran achieved the seventeenth place in the world steel producers and ranked first in the Middle East in terms of steel production. Also according to the World Steel Association, Iran's crude steel production growth rate in the first eight months of 2012 was greater than other major producers of crude steel in the world. This rate in Iran amounted to 9.3 percent while most steel producing countries have negative growth(World Steel Association, 2013).

Iran's crude steel production capacity at the end of the last Persian year (2011-2012) amounted to 20 million tons and it will increase to 43 million tons in this Persian year (2013-2014) based on the forecasted plan. In line with the country's 20-year vision plan, the annual steel production of 55 million tons has been anticipated for 2025-2026 which is not unexpected according to great mineral reserves (about 5 billion tons of exploration reserve and more than 2.5 billion tons of proven reserves)and vast reserves of energy, particularly gas and also manufacturing technology. Moreover, Iran'soperational capacity in iron ore in the Persian year 1384 (2005-2006) was 21 million tons which increased to 47 million tons at the end of the last Persian year (2012-2011). Iran's government plan for the Persian year 1392 (2013-2014) is to make capacity to harvest 100 million tons of iron orein the country. Given that the Middle East is the most important importer of steel due to higher consumption of steel than production, it imported about 30.4 million tons of steel in 2009. This could be an advantage for the steel industry in Iran. Therefore, a good consumer market is predictable for the country's steel products in the region.Iran'ssteel industry has always been of great importance from two perspectives: first, its industrial base and movement towards enhancing its infrastructures and second, creating sustainable jobs in the country. Hence part of the planning and movement towards development is based on steel. Looking at the 5-year development plans highlights the importance and status of the steel industry in the country. Steel as a leading industry plays an important role in the national economy and the development of other economic sectors, so its development is important as a basis for development of other industries so that experts relates a country's real industrial growth to the production of special steel types in that country.

According to statistics in Table 1, growth rate in iron ore mining is suitable but according to statisticsin Table 2 and Table 3, production rate of steel production and rollingsteel production is lower than that of raw materials for steel production.Sodecision makers must pay attention to higher investments in core activities of the organization and not to spend its resources and power for non-core activities.

According to the statistics in Table 2, the growth rate is associated with production fluctuations.Globalization has also led to severe competition in production and lower steel prices and consequently lower profit margin in this industry.It seems that a strategy for sustainable growth in this sector is to move toward outsourcing.This way, non-core activities and other non-economic activities are outsourced in order to achieve lower costs due to economies of scale.Moreover, the possibility of shiftingcosts from fixed costs to variable costs is provided and organizations have greater ability to predict costs and therefore plan activities and are incurred the lowest costs in case ofchanges in demand and the environment and have more compatibility with dynamic environments.

Today, given outsourcing benefits,companies are attempting to select suppliers to gain outsourcing benefits so that according to statistics, in 1977 manufacturing companies have reported that they have fully outsourced their remarkable activity (6% in parts design, 6% in product design, 9% in product assembly, 14% in parts manufacturing and 23%in packaging). It is also evident that in most cases,the spare parts production capacity of manufacturers that should be kept in the factory's technical stock will be higher than the limits that can be produced by the organization. In addition, diversity of necessary partsboth in terms of design and materials used will make the production of such parts in the volume requestedby a factory non-cost-effective for the organization. In such cases, signing contracts with manufacturers outside the organization will be perfectly cost-effective.

**Table 1 .Statistics of production of raw materials in steel (unit: ton) Iron ore Iran (2012)**

| Product Name | Performance of Ironstone Company of the Year | | | | |
|---|---|---|---|---|---|
| | 2007-8 | 2008-9 | 2009-10 | 2010-11 | 2011-12 |
| Ironstone production | 18,255,399 | 21,813,672 | 25,433,398 | 26,675,720 | 28,266,543 |
| Send and Sales | 21,378,173 | 25,280,385 | 21,766,815 | 30,863,108 | 26,387,817 |
| Extraction | 33,638,878 | 31,225,935 | 31,993,513 | 35,548,974 | 48,134,131 |

**Table 2 - Statistics of rolled steel production in Iran (unit: ton) Steel Iran (2012)**

| Product Name | Performance of rolledsteel production of the Year | | | | |
|---|---|---|---|---|---|
| | 2007-8 | 2008-9 | 2009-10 | 2010-11 | 2011-12 |
| Galvanized sheet | - | - | - | 250 | 82,254 |
| pipe | 19,916 | 27,985 | 23,096 | 26,561 | 31,148 |
| coil | 164,552 | 131,196 | 109,959 | 53,392 | 23,851 |
| Wide sheet | - | - | 66,553 | 336,100 | 313,844 |
| Beam | 1,844,445 | 1,739,739 | 1,797,598 | 2,025,493 | 1,873,010 |
| Round Bars | 3,012,204 | 3,220,976 | 2,992,240 | 3,311,013 | 313,844 |
| Hot-rolled sheet | 4,014,621 | 4,696,432 | 5,224,708 | 5,843,305 | 6,047,858 |
| Other | 12,520 | 21,524 | 21,923 | 17,236 | 21,797 |

**Table 3 - Statistics in steel production (unit: ton)Steel Iran (2012)**

| Product Name | Production of crude steel production during the year | | | | |
|---|---|---|---|---|---|
| | 2007-8 | 2008-9 | 2009-10 | 2010-11 | 2011-12 |
| Cast iron ingot | 272,546 | 100,646 | 142,429 | 70,089 | 35,492 |
| BILLET | 720,223 | 877,990 | 1,199,370 | 932,362 | 1,097,237 |
| BLOOM | 3,481,151 | 3,668,164 | 3,791,665 | 4,402,579 | 4,535,210 |
| SLAB | 5,743,065 | 5,836,387 | 5,532,198 | 6,427,245 | 7,159,339 |

On the one hand, government policies towards the country's 20-year vision plan in the development of the steel industry, the existence of huge reserves of raw materials and also enormous energy resources and human resources as desirable production conditions, and on the other hand,the existence of good prospects for domestic marketsand the existence of one of the key steel markets in the region have paved the way for the development of Iran's steel industry and will provide a clear vision for it. Thus, freeing the organization's resources and powerfrom non-core activities and allocating themto core activities can develop and increase its competition advantage, and effectiveness and efficiency of investment in the organization. It can also prevent opportunity cost caused by the lack of investment in core activities.

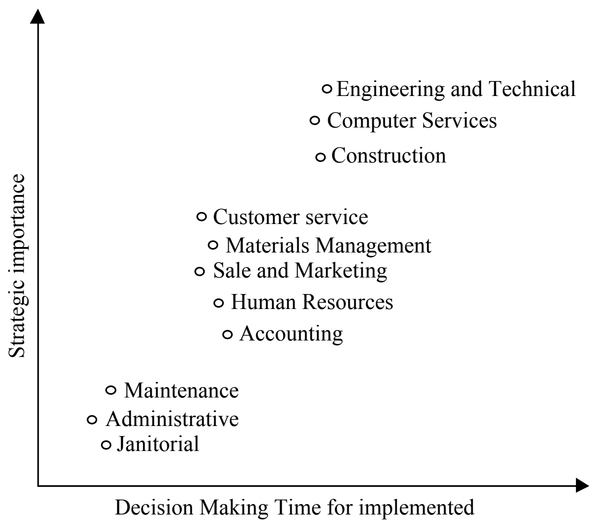


**Figure 1. Outsourcing Strategies (4)**

Figure.1 illustrates the importance of strategic decisions in technical-engineering and manufacturingareas. Given that outsourcing of mechanical partssupply is located in this area, decisions in this area are important in terms of strategy, complexity and the time required for decision-making.

The nature of these types of decisions is usually complex and unstructured and many quality and quantity performance criteria should be considered to determine the most appropriate supplier such as quality, financial strength, flexibility, and delivery time. This study uses verbal phrases, deterministic numbers, a range of numbers, a probability of numbers, and fuzzy numbers presented by experts to determine and evaluate the performance of each supplier against each criterion and to determine the weight of each criterion. Verbal ratings are expressed by trapezoidal fuzzy numbers and finally, the multi-criteria decision makingmethod (MCDM) is used in the fuzzy environment to rank suppliers.

## Criteria for supplier selection

Dickson (1966) proposed 23 indices for making decisions on supplier selection. Dickson also classified these criteria into four groups based on importance: Extreme Importance, Considerable Importance, Average Importance, and Slight Importance. On this basis, quality is introduced as an extreme important factor. Choyand Lee (2002) proposed three main criteria and 27 sub-criteria to introduce a generic tool for the selection and management of supplier relationships in an outsourced manufacturing environment. Accordingly, the quality assessment criterion accounted for the highest weight. Using a fuzzy multi-criteria decision method in evaluating suppliers, Boran *et al.*(2009) used four criteria (quality, relationship closeness, delivery performance and price) to evaluate suppliers. In studying more than 110 articles from 1966 to 2001 and article comparisons, Cheraghi, Dadashzadeh, and Suberamin (2004) suggest that one can see significant changes in the relative importance of critical success factors in the research published from 1966 to 1990 and from 1990 to 2001. Based on that study, in addition to traditional success criteria, changes in non-traditional factors in the market have become more important. Khaled *et al.* (2011) attempted to select supplier by proposing a supplier selection method through a multi-criteria decision technique by seven criteria (quality, delivery, production capacity, service, engineering capacity, business structure and price)with the Fuzzy Analytical Hierarchical Process method. Vaezi, Shahgholian, and Shahrakhi (2011) reviewed supplier selection techniques. They proposed a fuzzy multi-criteria grouped decision making method by examining AHP, DEA, GP, MOP, DEA, SMART, Fuzzy AHP, Fuzzy GA, Fuzzy SMART, and NN and by introducing a model in the form of four main criteria and 6 sub-criteria. Application of multi criteria decision making technique to evaluate suppliers in supply chain management, Zaeri*et al.* (2011) presented thirteen criteria (urgent delivery, on time delivery, ordering cost, warranty period, product price, financial stability, delivery lead time, accessibility, reliability, transportation cost, rejection of defective products, cost of support services, testability) in their model. Then they proceed to assess and rank five suppliers based on the TOPSIS method. Chen and Chao (2012) attempted to select suppliers with a method using consistent fuzzy preference relations. That study presented fifteen sub-criteria in the form of four main criteria as the research model. Based on the results, price and delivery criteria accounted for the highest value and then quality, supplier conditions, and professional techniques were ranked next. Kilincci and Onal (2011) acted to select suppliers in a washing machine company using the fuzzy AHP. For this purpose, they defined 14 sub-criteria in the form of supplier criteria, production performance criteria and service performance criteria and compared suppliers accordingly. Using the AHP approach in a steel manufacturing company, Tahriri *et al.* (2008) investigated the factors influencing supplier selection and evaluation. In that study, a model is presented with three criteria level. Six criteria were in the main criteria level, 16 in the first sub-criteria and 35 in the second sub-criteria. Based on the results, trust in the main criteria level has the most value. Yaghoubi, Baradaran,and Abdi(2011) provide 14 criteria in a supplier selection model in the supply chain based on AHP and GREY SYSTEMS THEORY in a case study in a cement manufacturing company. Based on the results, quality and then compliance in due time and guarantee too agreement had the highest value.

Due to different dimensions in selecting outsourcing of mechanical partssuch as multiple suppliers and lack of product price in decisionmaking for parts supply (over 55% of parts of the Iranian National Group) that require design and price estimation, that article classifies suppliers based on general criteria to identify the best suppliers commensurate with the part importance for negotiations and contract signing.Machinery factories of Iran National Steel Industrial Group (2012)

Differs from the above articles, the present research presents a multi-criteria decision method based on the Fuzzy Analytical Hierarchy Process (FAHP). The model design considers outsourcing goals, delivery terms and organizational policies in supplier selection.The model design also considers conditions for multiple sourcing at the options level. Finally, the study attempts to rank suppliers based on the proposed method of ranking fuzzy numbers. The use of the mentioned method leads to finding an unique solution which allows the decision maker to apply risk based on the importance of the decision subject (part type) (based on the calculation of confidence level for part type proposed by Budynas & Nisbett (2008) and proceed to select suppliers.

- It can be said that the following research objectives are achieved:
- To create competition among suppliers forofferingbetter price, quality and service,
- To avoid the risk of a supplier that has become strong,
- Non-stopsupply in case of unforeseen events,
- To create accessible capacities, to respond to future needs,
- Capacity inadequacy of any single supplier,
- Lack of development of suppliers,
- Testing the potential and abilities of new suppliers
- To offera systematic model to structure the decision process,
- To display tradeoff among criteria,
- To help decision makers reflect upon, articulate, and apply value judgments concerning acceptable tradeoffs, resulting in recommendations concerning alternatives,
- To help people make more consistent and rational evaluations of risk and uncertainty,
- To facilitate negotiations (increasing bargaining power),
- To document how decisions are made.

## Methodology

Thissection briefly describes the fuzzy set theory, AHP and fuzzy AHP and thenthe proposed method is presented.

### *Numbers and fuzzy sets*

Ever since humans began thinking, they have always used words and phrases with unclear boundaries. In reality, most phenomena, variables and concepts have non-deterministic, imprecise and vague nature and do not follow the principles governing normal anddeterministic set theory. By introducing the fuzzy sets theory in 1965, Zadeh(1965) first provided the basics of modeling imprecise information and approximate reasoning with mathematical equations which brought about a megatrend in classic mathematics and logic in its kind. The idea of fuzzy sets theory was introducedby these words of Prof. Lotfi Zadeh: “We need a different kind of mathematics to be able to model uncertainty and imprecision of events;a model which is different from probability theory.” So, the fuzzy theory emerged to describe the uncertainty and imprecision of events based on multi-valued logic.

### *AHP and Fuzzy AHP*

Analytical Hierarchy Process is one of the most popular multi-attribute decision techniques developed by Thomas L. Saati in 1970. This method analyses problems like what happens in the human brain. Analytical Hierarchy Process enables decision makers to determine simultaneous interactions of many complex and uncertain situations. This process helps decision-makers adjust priorities according totheir goals, knowledge and experience so that they fully consider their feelings and judgments. Tosolve decision problems through AHP, one should define and explain the problem carefully with all the details, and map the details in a hierarchical structure. However, the conventional AHP method has disadvantages in evaluating existing ambiguous situations (Bouyssou *et al.*, 2000) In 1983, two Dutch researchers named Laarhoven, and Pedrycz (1983) proposed the fuzzy AHP using the logic fuzzy method that was based on the logarithmic least squares method.But it was not welcomed by researchers because of its complexity and calculations. Other methods were then presented by “Buckley” and “Chang” based on AHP (Buckley, 1985; Chang, 1996). In this study,the hierarchical analysis of corrective Zeng, An, and Smith (2007) and a method of ranking fuzzy numbers was proposed Ezzati *et al.* (2012) which led to enhanced usability and performance of the proposed decision model. Here is a brief description of the Zeng method and its application by other researchers (Kahraman, Kaya, and Cebi, 2009; Kahraman, Beskese, and Kaya, 2010a;Kahraman and Kaya, 2010b; Kaya, 2012).

### *The proposed method*

**Step 1.** Decision-makers need to evaluate all information of the outsourcing selection problem which is addressed below. For various reasons, decision makers have different views which can affect the final decision. Therefore, a weighting method is used for calculating competency of decision makers in the model. For this purpose, senior managers are asked to assign a weight to each expert based on importance, expertise, knowledge and experience. Accordingly, for decision makers in the evaluation group, weight is assigned by decision makers for which $\sum_{i=1}^{m} c_i = 1$. Factors are measured hierarchically. Experts need to present their judgments based on their knowledge and experience for each factor at the end level of the hierarchy. Experts can present a deterministic numerical value, a set of numeric values;a quality expression or a fuzzy number.

**Step 2.** Compare factors (criteria) using paired comparisons. In this section, experts need to compare each factor paired-wiseand calibrate them in a fuzzy scale. Scale 1 to 9 is used for filling the paired comparisons matrix to determine the importance of each element relative to other elements in relation to that property. Table 4 shows this scale for paired comparisons.

**Table 4. Scale of relative importance Saaty (1980)**

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective. |
| 3 | Weak importance of one over another | Experience and judgement slightly favour one activity over another. |
| 5 | Essential or strong importance | Experience and judgement strongly favour one activity over another. |
| 7 | Demonstrated importance | An activity is strongly favoured and its dominance demonstrated in practice. |
| 9 | Absolute importance | The evidence favouring one activity over another is of the highest possible order of affirmation. |
| 2,4,6,8 | Intermediate values between the two adjacent judgements | When compromise is needed. |
| Reciprocals of above non-zero | If activity i has one of the above non-zero numbers assigned to it when compared with activity j , then j has the reciprocal value when compared with i | |

**Step 3.** Convert preferences into standard trapezoidal fuzzy numbers (STFN). As stated in steps 1 and 2, because the values provided by experts include deterministic numbers, a range of numbers, a linguistic word or a fuzzy number, STFN is used to convert judgments of these experts to a general format for comparing group preferences.

This article uses standard trapezoidal fuzzy numbers.A trapezoidal fuzzy number is defined as , as shown in Figure.2 and its membership function is as Eq. 1. This kind of numbers are the result of this concept that there are several points whose degree of membership is maximum α = 1.

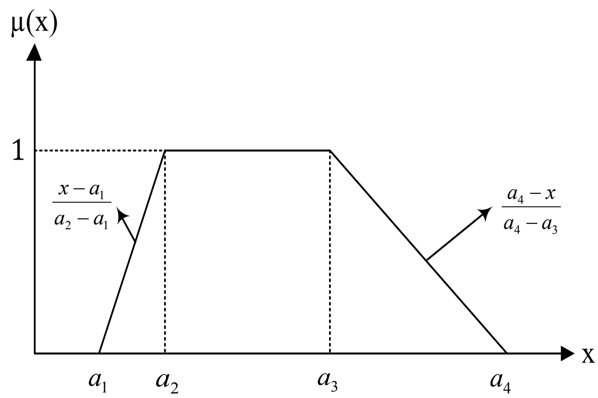


**Figure 2. Membership function of an STFN**

$$\mu_{(A)}(x)=\begin{cases}0, & x<a_1\\ \frac{x-a_1}{a_2-a_1}, & a_1\le x\le a_2\\ 1, & a_2\le x\le a_3\\ \frac{a_4-x}{a_4-a_3}, & a_3\le x\le a_4\\ 0, & x>a_3\end{cases} \quad (1)$$

How to convert expert opinions to standard trapezoidal fuzzy numbers:

- The deterministic number «m» is converted into the standard trapezoidal fuzzy number $\tilde{A}=(m,m,m,m)$.
- The linguistic word "k" is converted into the standard trapezoidal fuzzy number $\tilde{A}=$ цkнцkцk $k$ $k+$ .
- The range of two numbers, as "(m, n)", is converted into the standard trapezoidal fuzzy number $\tilde{A}=(m,m,n,n)$.
- The triangular fuzzy number, B (klm), is converted into the standard trapezoidal fuzzy number $\tilde{A}=(k,l,l,m)$.
- If the decision maker cannot do any comparisons between factors, then it will be shown by the standard trapezoidal fuzzy number $\tilde{A}=(0,0,0,0)$.
- The quality scale (linguistic words)"good" is converted intothe standard trapezoidal fuzzy number $\tilde{A}=(5,7.5,7.5,10)$.

The present study uses the scale shown in Figure.3 to convert linguistic words into STFN.

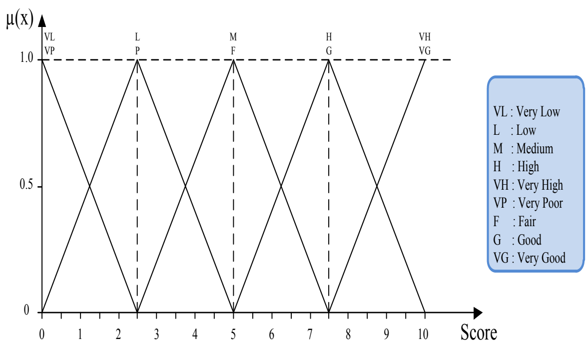


**Figure 3. Membership functions for evaluation.**

**Step 4.** Gather individual STFNs by Eq. 2 and Eq. 3 in groupedSTFNs. This step aims to gather individual preferences of experts in order to obtain grouped-priority for each factor.The STFN scores are gathered by averaging trapezoidal fuzzy numbers through Eq. 2.

$$\tilde{S}_i=\frac{\tilde{s}_{i1}\times c_1+\tilde{s}_{i2}\times c_2+\ldots+\tilde{s}_{im}\times c_m}{1-\sum c_r} \quad (2)$$

which is the grouped average of the gathered fuzzy numbers for factor in which $\tilde{s}_{i1}$, $\tilde{s}_{i2}$, ..., $\tilde{s}_{im}$ are the STFN scores of factor measured by experts $F_i$; ⊕ and⊗ are fuzzy multiplication and fuzzy summation; $c_1$, $c_2$, ..., $c_m$ are fuzzy participation factors associated with experts $E_1$, $E_2$, ...,$E_m$; and $\sum_{i=1}^{m} c_i=1$ which $\sum c_r$ is total weight of decision makers with no opinion for whom the standard trapezoidal fuzzy number (A) (0,0, 0, 0) is considered and the expert weight is subtract from the denominator.

Similarly, STFN scales are defined for each factor as follows.

$$\tilde{a}_{ij}=\frac{\tilde{a}_{ij1}\times c_1+\tilde{a}_{ij2}\times c_2+\ldots+a_{ijm}\times c_m}{1-\sum c_r} \quad (3)$$

Which $\tilde{a}_{ij}$ is the average fuzzy score $F_i$ compared to $F_j$; i, j = (1, 2, ..., n); and $\tilde{a}_{ijm}$, ... , $\tilde{a}_{ij2}$, $\tilde{a}_{ij1}$ are STFN scales associated with $F_i$ compared to $F_j$ measured by experts $E_m$ ... $E_2$, $E_1$, which $\tilde{a}_{ij1}$ is a fuzzy number for each criterion in paired comparisons by expert $k$; $c_j$ belongs to expert $j$ and $\sum c_r$ is total weight of decision makers with no opinion for whom the standard trapezoidal fuzzy number (A) (0,0, 0, 0) is considered and the expert weight is subtract from the denominator.

**Step 5.** Defuzzificate STFN scales. In order to convert total STFN scales into compatible deterministic number that can fully represent preferences, defuzzification needs to be done. Suppose a STFN scale with the total of $\tilde{a}_{ij}=a_{ij}^{l},a_{ij}^{m},a_{ij}^{n},a_{ij}^{u}$. A compatible deterministic value can be obtained by Eq. 4.

$$a_{ij}=\frac{a_{ij}^{l}+2(a_{ij}^{m}+a_{ij}^{n})+a_{ij}^{u}}{6} \quad (4)$$

which $a_{ii}$ = 1 and $a_{ji} = 1/a_{ij}$.

As a result, all fuzzy scales i, j = (1, 2, ..., n) in the range (0, 9) are converted into deterministic criteria.

**Step 6.** Calculate preferenceweightsforfactors. Let $F_n$ ... $F_2$, $F_1$, are the factor set of a section. are-non-fuzzy scales that define quantitative judgments compared to . Paired comparisons between $F_i$ and $F_j$ in the identity section of a n×n matrix is obtained using Eq. 5.

$$A=a_{ij}=\begin{matrix} \\ 0_0\\ A_1\\ A_2\\ \vdots\\ A_m\end{matrix}\begin{matrix} A_1 & A_2 & \cdots & A_n\\ \end{matrix}\begin{pmatrix}1 & a_{12} & \cdots & a_{1n}\\ 1/a_{12} & 1 & \cdots & a_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ 1/a_{1n} & 1/a_{2n} & \cdots & 1\end{pmatrix},\ i,j=1,2,\cdots,n \quad (5)$$

which $a_{ii}$ = 1 and $a_{ji} = 1/a_{ij}$.

The priority weights for elements in matrix A can be calculated using Eq. 6.

$$w_i = \frac{1}{n}\sum_{j=1}^{n}\frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}},\ i\ ,j = 1,2,\ldots,n\ . \qquad (6)$$

which $w_i$ is the weight of section $F_i$. Suppose $F_j$ is at different levels of the hierarchy, $w_{section}^{(i)}$ is the weight of a section from *ith*upper sections of $F_i$ in hierarchical levels. The final weight $w_i^{'}$ associated with $F_i$ can be calculated by Eq. 7.

$$w_i^{'} = w_i \times \prod_{i=1}^{t} w_{section}^{(i)} \qquad (7)$$

All weights in the upper sections $w_{section}^{(i)}$ are also calculated by Eq. 6in order to prioritize sections in the corresponding cluster in the hierarchy.

**Step 7.** Calculate the final fuzzy scores. When scores and weights forfactor prioritiesare obtained,the final fuzzy scores ( $\widetilde{FS}$ ) are calculated by Eq. 8

$$(\widetilde{FS}) = \sum_{i=1}^{n} \tilde{s}_i\, w_i^{l},\ i = 1,2,\ldots,n \qquad (8)$$

**Step 8.** In order to reach the final solution, ( $\widetilde{FS}$ ) are compared with each other using a value ranking method. The proposed method in the present study is the Ezzati ranking method presented in 2012 based on the Alpha Cut.(Ezzati, 2012) Accordingly, compare the values of fuzzy ( $\widetilde{FS}$ ) sand then calculate the ranking of numbers from the largest numerical value Mag to the smallest values for ( $\widetilde{FS}$ ) (using Eq. 9).

$$Mag(u) = \frac{1}{2}\int_0^1 (\underline{u}(\alpha) + \bar{u}(\alpha) + \underline{u}(1) + \bar{u}(1)) f(\alpha) d\alpha \quad (9)$$

Any fuzzy number is represented by an ordered pair of functions as $0 \le \alpha \le 1, (\underline{u}(\alpha), \bar{u}(\alpha))$ which apply in the following conditions.

1. $\underline{u}(\alpha)$ isa function that has left continuity, non-descending and is bound over the interval.

2. $\bar{u}(\alpha)$ isa function that has left continuity, non-ascending and is bound over the interval.

3. $0 \le \alpha \le 1, \underline{u}(\alpha) \le \bar{u}(\alpha)$

## Case Study

Machinery for various industries of the country have been bought or built in a long period by exorbitant costs so that it is believed that one-third of the country's assets (other than mines) is industrial machinery. These capitals, amounting to tens of thousands of tomans (billions of dollars), require more attention to the decisions made for supporting installations and machinery. Given the importance of decisions in this area, a systematic system is required to select the best supplier, as a strategic factor for the maintenance of these national capitalsand alsoas a key factor towards the organization's survival.

The lack of a suitable model for separating options in Iran National Steel Industrial Group has faced decision makers with ambiguous situations because a high percentage of the company's resources and power are devoted toparts supply. Moreover, the final product quality and costs, activities of production line process and the organization's survival are directly related to the quality (of supplying these parts) and quantity of the final costs of parts. So, modifying the decision process can be considered as a critical factorin the company's success in a competitive situation.

Thispaper ranks mechanical parts suppliers of Iran National Steel Industrial Group using the fuzzy multi-criteria decision method based on Analytic Hierarchy Process (AHP). For this purpose, 5 experts were appointed by the organization's top decision makers; 2 experts from the Machining Unit, 2 experts from the Contracts Unit and 1 expert from the Quality Control Unit were designated as the decision maker. The research's sub-criteria and hierarchy (conceptual model) were set according to the literature, expert opinions and organizationalpolicies.

### *Hierarchical structure and parameters of the model*

There is no specific rule to establish a hierarchy. So, one can consider establishing the decision hierarchy as an innovative and creative process. The hierarchical model for outsourcing decisions was established using the "AHP" technique and considering the organization's policy factors, delivery, quality and support,and executive infrastructures. In this model (Figure. 4), each factor has a series of criteria that can explain its significance.

Criteria for the decision model are as follows:

1. Organizational policies
   i. Geographical location
   ii. Accountability and communication
   iii. Good experience
   iv. Flexibility
2. Delivery
   i. Delay
   ii. Shortage
   iii. Unconformity
3. Quality and support
   i. Post sales services

ii. Quality of products
iii. Certificates
4. Executive infrastructures
i. Technological power
i. Machinery (hardware or physical tools)
ii. Human power
iii. Technical knowledge
ii. Executive power
i. Production capacity
ii. Financial power

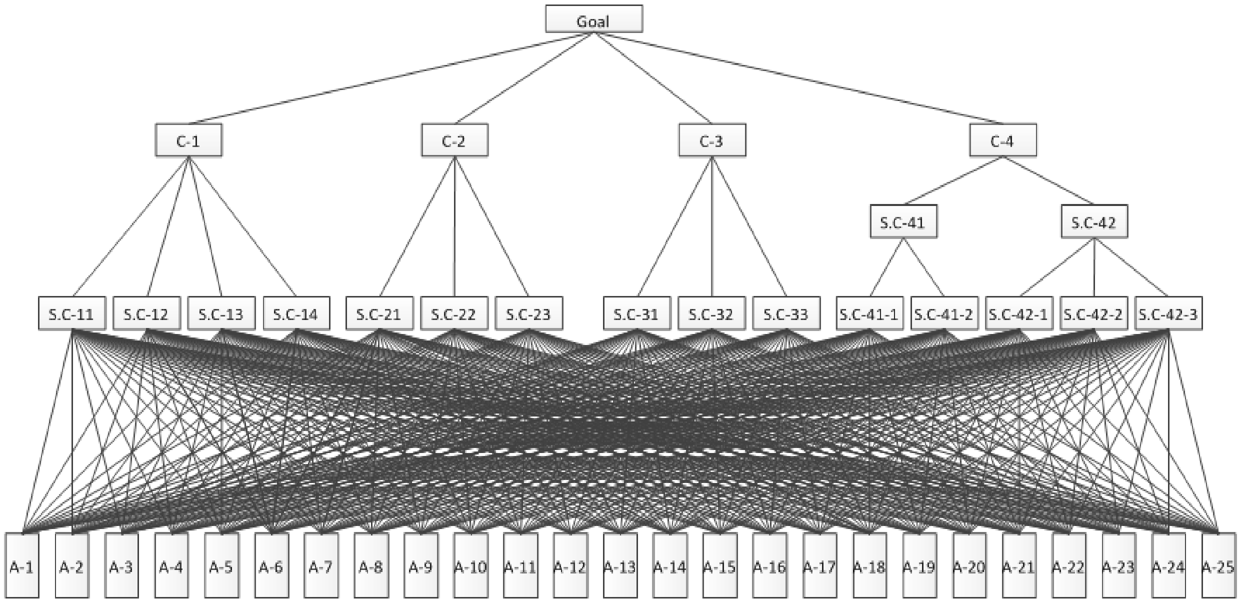


**Figure 4. Conceptual model of research (hierarchical structure for Alternative to outsource parts makers)**

### *Application of the proposed method*

At the first stage, senior decision makers were askedto express the competence of each member of the decision group. After a short discussion, identical weight was considered for members. Thus, the weight of each expert was considered 0.20. Then,criteria were evaluated to select the best option for outsourcing mechanical parts manufacturers. Accordingly, 4 main criteria and 17 sub-criteria were defined in which the main criterion of executive infrastructures had two sub-criterion levels and the other three main criteria had one sub-criterion level. Moreover, 25 options were defined at the end level of the hierarchy, as shown in Figure 4. Each option in the hierarchy is evaluated by experts under the definedhierarchy. Each expert makes decision based on his/her judgment as an exact numerical value, aprobabilistic range of numeric values, a range of two numbers, a linguistic expression or a fuzzy number.

Table 6 shows the scores and STFN converted for supplier 1 based on the research hierarchy criteria. The total STFN is calculated using Eq. 2. For example, for the flexibility sub-criterion, the *organizational policies* main criterion, we have:

$$\tilde{s}_{Flexibility} = [\ (9,9,9,9)\otimes\ 0.20\ \oplus\ (8,8,8,8)\otimes\ 0.20\ \oplus\ (6,6,7,7)\otimes\ 0.20\ \oplus\ (5,7.5,7.5,10)\otimes\ 0.20\ \oplus\ (7.5,10,10,10)\otimes\ 0.20\ ]\ /\ (\ 1-0\ ) = (7.1,\ 8.1,\ 8.3,\ 8.8\ )$$

According to the calculations made, total value of other criteria for supplier 1 is shown in Table 5.

Paired comparisons for the organizational policies and the STFN are shown in Table 6. Paired comparisons of the organizational policies criterion are made by Eq. 3. Accordingly, for total STFN of geographical location compared to communication and accountability, we have:

$$\tilde{a}_{12} = [\ (\ 1/5,\ 1/5,\ 1/4,\ 1/4)\otimes 0.20 \oplus (6,\ 6,\ 7,\ 7)\otimes 0.20 \oplus (1/3,\ 1/3,\ 1/3,\ 1/3)\otimes 0.20 \oplus (1/4,\ 1/4,\ 1/3,\ 1/3)\otimes 0.20 \oplus (7,\ 7,\ 8,\ 8)\otimes 0.20\ ]\ /\ (\ 1-0\ ) = (3.69,\ 3.69,\ 4.117,\ 4.117\ )$$

The obtained STFN scales must become non-fuzzy. The calculated STFN scales for geographical location compared to communication and accountability using Eq.4 are as follows:

$$\tilde{a}_{12} = \frac{3.69 + 2(3.69 + 4.117) + 4.117}{6} = 3.904$$

Using Eq. 4 and Eq. 5,the paired comparisons matrix is obtained for the organizational policies criteria as follows:

$$A_{\text{Organizational policies}} = \begin{bmatrix} 1.000 & 3.904 & 2.268 & 1.695 \\ 1.698 & 1.000 & 1.300 & 1.100 \\ 2.570 & 0.850 & 1.000 & 1.200 \\ 2.042 & 0.950 & 0.900 & 1.000 \end{bmatrix}$$

By examining this matrix and using Eq. 6,the weights of the sub-criteria associated with the *organizational policy* main criterion are calculated as follows:

$$w = \{0.368\ ,0.21\ ,0.225\ ,0.196\}$$

Weightsfor main criteria and sub-criteria are shown in Table 7.

Finalweights for values are calculated using Eq. 7. After calculation, $(\widetilde{FS})$ for supplier 1 is obtained using Eq. 8 as follows.

$$(\widetilde{FS}) = (6.5529\ ,7.981\ ,8.0058\ ,8.8691\ )$$

$(\widetilde{FS})$ valuesfor other suppliers were also calculated. The results are shown in Table 8-a.

In the last step of the proposed method,fuzzy scores must be ranked.To rank fuzzy scores, the proposed method in step 8 was used.(Eq. 9) The ranking results are presented in Table 8-b.

According to the results,we come to the conclusion that ranking of suppliers based on the model criteria and the implementation of the mentioned steps in thismodel are likeTable 8-b. As can be seen,supplier 10 with maximum Mag value is in the first place and supplier 16 with minimum Mag value is in the last place.

**Table 5. Experts on Standards and Privileges into trapezoidal fuzzy numbers and calculate the average standard for supplier 1 comments**

| Criteria | Sub Criteria Score | E-1 STFN | E-1 Score | E-2 STFN | E-2 Score | E-3 STFN | E-3 Score | E-4 STFN | E-4 Score | E-5 STFN | E-5 Score | Aggregated STFN |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Organizational policies | Geographical location | 8 | (8,8,8,8) | 7 | (7,7,7,7) | V G | (7.5,10,10,10) | V G | (7.5,10,10,10) | V G | (7.5,10,10,10) | (7.5, 9, 9,9) |
| Organizational policies | Accountability and communication | 9 | (9,9,9,9) | 7 | (7,7,7,7) | G | (5,7.5,7.5,10) | V G | (7.5,10,10,10) | V G | (7.5,10,10,10) | (7.2, 8.7, 8.7,9.2) |
| Organizational policies | Good experience | 9 | (9,9,9,9) | 8 | (8,8,8,8) | G | (5,7.5,7.5,10) | V G | (7.5,10,10,10) | V G | (7.5,10,10,10) | (7.4, 8.9, 8.9,9.4) |
| Organizational policies | Flexibility | 9 | (9,9,9,9) | 8 | (8,8,8,8) | B(6,7) | (6,6,7,7) | G | (5,7.5,7.5,10) | V G | (7.5,10,10,10) | (7.1, 8.1, 8.3,8.8) |
| Delivery | Delay | 8 | (8,8,8,8) | 8 | (8,8,8,8) | M | (2.5,5,5,7.5) | L | (5,7.5,7.5,10) | L | (5,7.5,7.5,10) | (5.7, 7.2, 7.2,8.7) |
| Delivery | Shortage | 8 | (8,8,8,8) | 8 | (8,8,8,8) | V L | (7.5,10,10,10) | L | (5,7.5,7.5,10) | V L | (7.5,10,10,10) | (7.2, 8.7, 8.7,9.2) |
| Delivery | Unconformity | 9 | (9,9,9,9) | 7 | (7,7,7,7) | M | (2.5,5,5,7.5) | L | (5,7.5,7.5,10) | L | (5,7.5,7.5,10) | (5.7, 7.2, 7.2,8.7) |
| Quality and support | Post sales services | A(5) | (4,5,5,6) | 6 | (6,6,6,6) | V L | (0,0,0,2.5) | B(5,6) | (5,5,6,6) | M | (2.5,5,5,7.5) | (3.5, 4.2, 4.4,5.6) |
| Quality and support | Quality of products | 8 | (8,8,8,8) | 6 | (6,6,6,6) | G | (5,7.5,7.5,10) | G | (5,7.5,7.5,10) | G | (5,7.5,7.5,10) | (5.8, 7.3, 7.3,8.8) |
| Quality and support | Certificates | 9 | (9,9,9,9) | 7 | (7,7,7,7) | G | (5,7.5,7.5,10) | G | (5,7.5,7.5,10) | V G | (7.5,10,10,10) | (6.7, 8.2, 8.2,9.2) |
| Executive infrastructures – Technological power | Machinery | 6 | (6,6,6,6) | 7 | (7,7,7,7) | G | (5,7.5,7.5,10) | G | (5,7.5,7.5,10) | G | (5,7.5,7.5,10) | (5.6, 7.1, 7.1,8.6) |
| Executive infrastructures – Technological power | Human power | 7 | (7,7,7,7) | 6 | (6,6,6,6) | G | (5,7.5,7.5,10) | V G | (7.5,10,10,10) | G | (5,7.5,7.5,10) | (6.1, 7.6, 7.6,8.6) |
| Executive infrastructures – Technological power | Technical knowledge | 9 | (9,9,9,9) | 7 | (7,7,7,7) | V G | (7.5,10,10,10) | V G | (7.5,10,10,10) | G | (5,7.5,7.5,10) | (7.2, 8.7, 8.7,9.2) |
| Executive infrastructures – Executive power | Production capacity | 9 | (9,9,9,9) | 8 | (8,8,8,8) | B(6,7) | (6,6,7,7) | V G | (7.5,10,10,10) | V G | (7.5,10,10,10) | (7.6, 8.6, 8.8,8.8) |
| Executive infrastructures – Executive power | Financial power | 9 | (9,9,9,9) | 8 | (8,8,8,8) | B(6,7) | (6,6,7,7) | V G | (7.5,10,10,10) | V G | (7.5,10,10,10) | (7.6, 8.6, 8.8,8.8) |

**Table 6. Paired comparisons based on the following criteria, policy experts**

| | | Geographical location | | Accountability and communication | | Good experience | | Flexibility | |
|---|---|---|---|---|---|---|---|---|---|
| | | Score | STFN | Scale | Converted STFN | Scale | Converted STFN | Scale | Converted STFN |
| Geographical location | 1 | | | 0.2, 0.25 | (0.2, 0.2, 0.25, 0.25) | 0.14,0.17 | (0.14, 0.14, 0.17, 0.17) | 0.17,0.2 | (0.17, 0.17, 0.2, 0.2) |
| | 2 | | | 6,7 | (6,6,7,7) | 3,4 | (3,3, 4, 4) | 2,3 | (2, 2, 3, 3) |
| | 3 | | | 5 | (5,5,5,5) | 3 | (3, 3, 3, 3) | 2 | (2, 2, 2, 2) |
| | 4 | | | 0.25,0.33 | (0.25, 0.25, 0.33, 0.33) | 0.17,0.2 | (0.17, 0.17, 0.2, 0.2) | 0.25,0.33 | (0.25, 0.25, 0.33, 0.33) |
| | 5 | | | 7,8 | (7, 7, 8, 8) | 4,5 | (4, 4, 5, 5) | 3,4 | (3,3,4,4) |
| | Aggregation | | (1,1,1,1) | | (3.69, 3.69, 4.117,4.117) | | (2.062, 2.062, 2.473, 2.473) | | (1.483, 1.483, 1.907, 1.907) |
| Accountability and communication | 1 | 4,5 | (4, 4, 5, 5) | | | 1,2 | (1, 1, 2, 2) | 1,2 | (1,1, 2, 2) |
| | 2 | 0.14,0.17 | (0.14, 0.14, 0.17, 0.17) | | | 1,2 | (1,1, 2, 2) | 1 | (1,1,1,1) |
| | 3 | 0.2 | (0.2, 0.2, 0.2, 0.2) | | | 1 | (1,1,2,2) | 1 | (1,1,1,1) |
| | 4 | 3,4 | (3, 3, 4, 4) | | | 1 | (1,1,1,1) | 1 | (1,1,1,1) |
| | 5 | 0.13,0.14 | (0.13, 0.13, 0.14, 0.14) | | | 1,2 | (1, 1, 2, 2) | 1 | (1,1,1,1) |
| | Aggregation | | (1.494, 1.494, 1.902,1.902) | | (1,1,1,1) | | (1, 1, 1.6,1.6) | | (1, 1, 1.2, 1.2) |
| Good experience | 1 | 6,7 | (6,6,7,7) | 0.5,1 | (0.5, 0.5, 1, 1) | | | 1 | (1,1,1,1) |
| | 2 | 0.25,0.33 | (0.25, 0.25,0.33,0.33) | 0.5,1 | (0.5, 0.5, 1, 1) | | | 1,2 | (1, 1, 2, 2) |
| | 3 | 0.33 | (0.33,0.33,0.33,0.33) | 1 | (1,1,1,1) | | | 1 | (1,1,1,1) |
| | 4 | 5,6 | (5,5,6,6) | 1 | (1,1,1,1) | | | 1,2 | (1, 1, 2, 2) |
| | 5 | 0.2,0.25 | (0.2, 0.2, 0.25, 0.25) | 0.5,1 | (0.5, 0.5, 1, 1) | | | 1 | (1,1,1,1) |
| | Aggregation | | (2.357, 2.357, 2.783,2.783) | | (0.7, 0.7, 1,1) | | (1,1,1,1) | | (1, 1, 1.4, 1.4) |
| Flexibility | 1 | 5,6 | (5,5,6,6) | 0.5,1 | (0.5, 0.5, 1, 1) | 1 | (1,1,1,1) | | |
| | 2 | 0.33,0.5 | (0.33, 0.33, 0.5, 0.5) | 1 | (1,1,1,1) | 0.5,1 | (0.5, 0.5, 1, 1) | | |
| | 3 | 0.5 | (0.5, 0.5, 0.5, 0.5) | 1 | (1,1,1,1) | 1 | (1,1,1,1) | | |
| | 4 | 3,4 | (3,3,4,4) | 1 | (1,1,1,1) | 0.5,1 | (0.5, 0.5, 1, 1) | | |
| | 5 | 0.25,0.33 | (0.25,0.25,0.33,0.33) | 1 | (1,1,1,1) | 1 | (1,1,1,1) | | |
| | Aggregation | | (1.817, 1.817, 2.267,2.267) | | (0.9, 0.9, 1,1) | | (0.8, 0.8, 1, 1) | | (1,1,1,1) |

**Table 7. Weight of main criteria and sub-criteria**

| Criteria | Weight | Sub Criteria | Weight | Sub Criteria | Weight | FinalWeight |
|---|---|---|---|---|---|---|
| Organizational policies | 0.281 | - | - | Geographical location | 0.368 | 0.103 |
| | | - | - | Accountability and communication | 0.21 | 0.059 |
| | | - | - | Good experience | 0.225 | 0.063 |
| | | - | - | Flexibility | 0.196 | 0.055 |
| Delivery | 0.238 | - | - | Delay | 0.286 | 0.068 |
| | | - | - | Shortage | 0.328 | 0.078 |
| | | - | - | Unconformity | 0.385 | 0.092 |
| Quality and support | 0.326 | - | - | Post sales services | 0.093 | 0.030 |
| | | - | - | Quality of products | 0.335 | 0.109 |
| | | - | - | Certificates | 0.572 | 0.186 |
| Executive infrastructures | 0.155 | Technological power | 0.753 | Machinery | 0.205 | 0.024 |
| | | | | Human power | 0.466 | 0.054 |
| | | | | Technical knowledge | 0.328 | 0.038 |
| | | Executive power | 0.247 | Production capacity | 0.676 | 0.026 |
| | | | | Financial power | 0.324 | 0.012 |

**Table 8. S final fuzzy ( $(\widetilde{FS})$ ) and Mag calculated and ranked Options**

| Alternative | a | | | | b | |
|---|---|---|---|---|---|---|
| | $(\widetilde{FS})$ | | | | Result | |
| | $a_1$ | $a_2$ | $a_3$ | $a_4$ | Mag | Ranking |
| A-1 | 6.552932 | 7.981044 | 8.00578 | 8.869103 | 7.946346 | 3 |
| A-2 | 6.666291 | 8.001041 | 8.052106 | 8.793321 | 7.977112 | 2 |
| A-3 | 6.084716 | 7.430482 | 7.479066 | 8.458019 | 7.424206 | 9 |
| A-4 | 5.271083 | 6.605834 | 6.670395 | 7.757623 | 6.617487 | 21 |
| A-5 | 5.488216 | 6.822966 | 6.885047 | 7.960312 | 6.832383 | 20 |
| A-6 | 5.041736 | 6.376487 | 6.427552 | 7.487758 | 6.379141 | 23 |
| A-7 | 6.413682 | 7.750913 | 7.813208 | 8.698654 | 7.744412 | 4 |
| A-8 | 5.367964 | 7.028822 | 7.119625 | 8.576415 | 7.057218 | 15 |
| A-9 | 5.318333 | 6.998141 | 7.054158 | 8.475426 | 7.004604 | 16 |
| A-10 | 6.864406 | 8.199156 | 8.245045 | 8.954263 | 8.169973 | 1 |
| A-11 | 6.208032 | 7.542782 | 7.606681 | 8.479064 | 7.536201 | 7 |
| A-12 | 6.079517 | 7.431908 | 7.491507 | 8.12533 | 7.401827 | 11 |
| A-13 | 5.489617 | 6.850541 | 6.877758 | 7.894218 | 6.835444 | 19 |
| A-14 | 4.703177 | 6.037927 | 6.086512 | 7.223845 | 6.045768 | 24 |
| A-15 | 6.101228 | 7.445074 | 7.501091 | 8.453425 | 7.440457 | 8 |
| A-16 | 4.731514 | 5.845069 | 5.908665 | 6.9088 | 5.867415 | 25 |
| A-17 | 5.529321 | 6.858008 | 6.920088 | 8.134166 | 6.879497 | 18 |
| A-18 | 6.220983 | 7.361067 | 7.417084 | 8.134653 | 7.353866 | 12 |
| A-19 | 6.279024 | 7.613774 | 7.675854 | 8.536343 | 7.605292 | 6 |
| A-20 | 6.089216 | 7.423966 | 7.467374 | 8.347004 | 7.407744 | 10 |
| A-21 | 5.776778 | 7.111529 | 7.210953 | 8.142287 | 7.127623 | 14 |
| A-22 | 5.906872 | 7.255119 | 7.303703 | 8.242644 | 7.245302 | 13 |
| A-23 | 6.373547 | 7.723456 | 7.785536 | 8.718689 | 7.719767 | 5 |
| A-24 | 5.242236 | 6.355791 | 6.456731 | 7.357056 | 6.388492 | 22 |
| A-25 | 5.833267 | 6.956882 | 7.017998 | 8.028193 | 6.977988 | 17 |

## Conclusions

Decisions in this area are considered as an important factor in the organization's survival due to the following reasons: a high volume of assets in each country is industrial machinery and installations, the nature of the decisions in this area due to diversity of parts and the need to order parts for design and manufacture and the high number of decisions and requests (approximately 40,000 units of parts per year at Iran National Steel Industrial Group), the supply conditions of these parts and the importance of these decisions in organizational activities and the damaging effects caused by improper decisions in this area and the effects of these decisions on the quality and finished cost of products.

Considering the benefits of outsourcing for reducing costs in order to supply parts that has no value at the production scale or are produced with higher costs in the organization, and due to outsourcing parts to outside, the organization can achieve higher quality parts because of accessing to a broader level of knowledge, expertise and technology which is impossible for the organizations to achieve this level using internal resources and power. Outsourcing non-core activities allows the organization to devote its resources and power to core activities that have competitive advantage.

Outsourcing also allows the organization to shift its costs from fixed costs to variable costs which allows the organization to predict costs and thus planning. Given outsourcing benefits, today private and government (public) companies, governments, and educational institutions act to select suppliers for outsourcing. So, selecting the best outsourcing option is of great importance. This paper proposed a fuzzy MCDM method which allows the decision maker to express his/her opinions with more flexibility as deterministic numbers, a probability of numbers, a range of numbers, fuzzy numbers, linguistic words or if he/she has no opinion on the subject in calculations. Given the nature of decision-making in the parts supply for machinery and equipment of factories, which requires a model that can evaluate various suppliers to take advantage of multiple sourcing with an efficient method, this model considers above items. According to the results (Table 8-b), commensurate with parts, the organization can identify appropriate suppliers for negotiations and finally, contract signing for outsourcing. This way, the organization can reduce the uncertainty and complexity of decisions in this area. Moreover, the main criteria were as follows based on the results: {quality and support 32.6%, organizational politics 28.1%, delivery 23.8%, executive infrastructures 15.5%}.

Given that multi-criteria decision making includes new and numerous methods like REGIME AND SIR, future studies are recommended to use these methods and compare results with this method. To select appropriate suppliers for different parts, decision makers are faced with different risks proportionate with the decision subject, so researchers are suggested to design a model to help decision makers take risks in the supplier selection process given the importance of the decision.

## References


Boran, F.E., Cenc, S., Kurt, M., Akay, D. (2009). A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method. *Expert Systems with Applications, 36,* 11363-11368.

Bouyssou, D., Marchant, T., Pirlot, M., Perny, P., Tsoukias, A., Vincke, P. (2000). *Evaluation models: a critical perspective.* Boston: Kluwer;.

Buckley, J. J. (1985). Fuzzy hierarchical analysis. *Fuzzy Sets and Systems, 17,* 233–247.

Budynas, R.G.and Nisbett, J.K. (2008). *Shigley's Mechanical Engineering Design* (Eighth Edition). McGraw-Hill.

Chang, D. Y. (1996). Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research, 95,* 649–655.

Chen, Y.H., Chao, R.J. (2012) .Supplier selection consistent fuzzy preference relations. *Expert Systems with Applications, 39,* 3233-3240.

Cheraghi, H., Dadashzadeh, M., Subramanian, M. (2004). Critical Success Factors For Supplier Selection : An Update. *Journal of Applied Business Research, 20*(2), 91–108.

Choy, K.L., and Lee, W.B. (2002). A Generic Tool for the Selection andManagement of Supplier Relationships in an Outsourced ManufacturingEnvironment. *Journal of Logistics Information Management, 15*(4), 235-253.

Dickson, G. W. (1966). An analysis of vender selection systems & decisions. *Journal of Purchasing, 2*(1), 5–20.

Ezzati, R., Allahviranloo, T., Khezerloo, S., Khezerloo, M. (2012). An approach for ranking of fuzzy numbers. *Expert Systems with applications, 39,* 690–695.

Iron ore Iran (2012). *Statistics iron ore 1389-90.* http://www.imidro.gov.ir/Statistics/ironore-1390-esfand-monthly.pdf

Kahraman, C., Beskese, A., Kaya, I. (2010)a. Selection among ERP outsourcing alternatives using a fuzzy multi-criteria decision making methodology. *International Journal of Production Research, 48*(2), 547-566 .

Kahraman, C., Kaya, I. (2010)b. A fuzzy multicriteria methodology for selection among energy alternatives. *Expert Systems with Applications, 37*(9), 6270–6281.

Kahraman, C., Kaya, I., Cebi S. (2009). A comparative analysis for multiattribute selection among renewable energy alternatives using fuzzy axiomatic design and fuzzy analytic hierarchy process. *Energy, 34,* 1603–1616.

Kaya, I. (2012). Evaluation of outsourcing alternatives under fuzzy environment for waste management.Resources, *Conservation and Recycling, 60,* 107 – 118.

Khaled, A. A., Paul, S. K., Chakraborty, R. K., Ayuby, M.S. (2011). Selection of Suppliers through Different Multi-Criteria Decision Making Techniques. *Global Journal of Management and Business Research, 11* (4), 1 – 12.

Kilincci, O., Onal, S.A. (2011). Fuzzy AHP approach for supplier selection in a washing machine company. *Expert Systems with Applications, 38,* 9656-9664.

Laarhoven, P.J.M. , Pedrycz, W. (1983). A fuzzy extension of Saaty's priority theory. *Fuzzy Sets and Systems, 11,* 229–241.

Machinery factories of Iran National Steel Industrial Group (2012) . *Manufactured components* .http://www.insig.ir/tabid/79/Default.aspx

Saaty, T. L. (1980). *The analytic hierarchy process: Planning, priority setting & resource allocation*. New York: McGraw-Hill.

Steel Iran (2012). *Statistics steel 1390*. http://www.imidro.gov.ir/Statistics/steel-1390-esfand-monthly.pdf

Tahriri, F., Osman, M. R., Ali, A., Yusuff, R. M., Esfandiary, A. (2008).AHP approach for supplier evaluation and selection in a steel manufacturing company. *Industrial Engineering and Management , 1*(2) , 54-76.

Vaezi, Z., Shahgholian, K., Shahraki, A. (2011). A Model for Supplier Selection Based on Fuzzy Multi-Criteria Group Decision Making. *Scientific Research, 63*(1), 63–72.

World Steel Association (2013). Statistics steel 2012. http://www.worldsteel.org/statistics/statistics-archive/2012-steel-production.html

Yaghoubi, N. M., Baradarn, V., Abdi, M. (2011). Planning a model for supplier selection with AHP and Grey systems theory. *Business and Management, 1*(7), 09-19.

Zadeh, L. A. (1965). Fuzzy sets. *Information and Control, 8,* 338–353.

Zaeri, M. S., Sadeghi, A., Naderi, A., Kalanaki, A., Fasihy, R., Shorshani, S. M. H., Poyan, A. (2011). Application of multi criteria decision making technique to evaluation suppliers in supply chain management. *Mathematics and Computer Science Research, 4*(3), 100–106.

Zeng, J., An, M., Smith, N. J. (2007). Application of a fuzzy based decision making methodology to construction project risk assessment. *International Journal of Project Management, 25,* 589–600.