A FUZZY HYBRID AND INTEGRATED MCDM-LP MODEL FOR SINGLE AND MULTI-OUTSOURCING

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Abstract: Acquiring competitive advantage is a main key for business success in today's rapidly changing and uncertain environments and outsourcing has become an important approach in this regard. This article outlines a hybrid method to select the best supplier in single outsourcing approach and/or split order and allocate optimum order quantity to different suppliers under a fuzzy environment. The presented model incorporates fuzzy AHP, TOPSIS and LP techniques for group decision making while it takes different background of decision-making group members in to account. A case study of supplier selection in an optical company in Iran is presented.
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1. Introduction

Supplier selection is one of the critical activities for firms to gain competitive advantage and achieve the objectives of the whole supply chain. On average, manufacturers' purchases of goods and services constitutes up to 70% of product cost and in high technology firms, purchased materials and services represent up to 80% of total product cost (Ghodsypour et al, 2001). Furthermore, decision makers' interest about the supplier selection process has been continuously growing because reliable suppliers enable the reduction of inventory costs and the improvement of product quality (Braglia et, 2000). Indeed the supplier selection includes two issues: First, which supplier must be selected and the amount of purchasing from each of them must be determined. Solutions to these two questions reduce costs and improve competitive situation of the organizations.[19] On the other hand, supplier selection is a multiple criteria decision-making (MCDM) problem affected by several conflicting factors such as price, quality and delivery. A study carried out by Dickson based on a questionnaire sent to 273 purchasing agents identified 23 different commonly used criteria for supplier selection problem. Out of the 23 factors, Dickson concluded that quality, delivery and performance history are the most important criteria (Dickson, 1966). A latter review by Weber et al (1991) reported that over half of 74 research papers reviewed addressed the supplier selection problem with multiple criteria. In general, there is an agreement in relevant literature that selecting appropriate suppliers is a complicated issue because of the large number of criteria to be considered as well as because criteria are both quantitative (e.g. price, distance, delivery time) and qualitative (e.g. quality, design/technological capability, finances).

Many companies have redefined their position in the supply chain in an effort to face the consequences of the ongoing globalization of competition. Decisions to expand in certain parts of the chain and to subcontract other activities are increasingly taken in a global perspective (Grossman et al, 2005). Outsourcing practices have been recognized to have advantages, e.g. higher quality of service, lower cost of services in the long term, gain specialist expertise and skills that are not available in-house, managers have more time to concentrate on higher priorities, as well as disadvantages, e.g. perceived loss of control, transaction costs (e.g. the cost of searching for possible suppliers, tendering), monitoring costs (e.g. if outsourced suppliers require more monitoring than in-house), security risks/threats to confidentiality, loss of in-house skills/expertise (Hassanain et al, 2005).

Basically there are two kinds of supplier selection problem. In the first kind of supplier selection, one supplier can satisfy all the buyer's needs (single sourcing). The management needs to make only one decision: which supplier is the best. In the second type (multiple sourcing), no supplier can satisfy all the buyer's requirements. In such circumstances management wants to split order quantities among suppliers for a variety of reasons including creating a constant environment of competitiveness (Ghodsypour et al, 1998). A classic example is Alcatel. Alcatel has outsourced supply chain management and R&D functions to Wipro, and its SAP and ERP environment work to Infosys (Pinto, 2005). Some advantages and disadvantages of both approaches are shown in table 1.

Table 1- Some advantages and disadvantages of single and multi-outsourcing outsourcing (Ford, 2011)

Single Outsourcing		*Multi-Outsourcing*	
Advantages	*Disadvantages*	*Advantages*	*Disadvantages*
supplier is refailure of service delivery	dependence to one supplier	foster competition between suppliers	High risk due to delegate the responsibility to several suppliers
release from day-to-day monitoring and operating of the outsourcing	Possible not working relationship	using vendor specialization and technical expertise	Duplicated responsibilities and increasing costs
Long-term contract	lack of control on suppliers	reducing the risk of dependence to single supplier	Complicated process information flow between parties
Reduced contract management overheads	possible poor supplier's performance	Enhances service delivery due to competition	Spending resources and management time to resolving issues

Over the years, several techniques have been developed to solve the problem efficiently. Analytic hierarchy process (AHP), analytic network process (ANP), linear programming (LP), mathematical programming, multi-objective programming, data envelopment analysis (DEA), neural networks (NN), case-based reasoning (CBR) and fuzzy set theory (FST) methods have been applied in literature. Also, the integration of different methodologies has been developed in literature and the integration takes the advantages of various methods' strengths and complements their weaknesses (Guneri, 2009).

However, under many conditions, crisp data are inadequate to model real-life situations. Since human judgments, including preferences, are often vague and cannot estimate his preference with an exact numerical value. A more realistic approach maybe to use linguistic assessments instead of numerical values. In other words, the ratings and weights of the criteria in the problem are assessed by means of linguistic variables (Bellman et al, 1970).

Despite many research works during past decades on the supplier selection issue, it is still a fresh subject in academic studies. This is due to complexity nature of supplier selection which involves many tangible and intangible criteria in one hand and the importance of supplier selection in gaining the competitive advantages of company in the other hand.

Zouggari, A. et al (2011) have proposed a multi-criteria group decision supplier selection problem using fuzzy TOPSIS based approach. They have supposed K potential suppliers, a unique distribution center (DC) and a unique market (customer). In their model after aggregation of group decisions, suppliers select by fuzzy AHP method. Then, in order to update the database (i.e. new values of criteria; evaluation of the stock level, etc.) a simulation process is used and order allocation is the final step.

Bagheri, F. et al (2010) developed a fuzzy approach for multi-objective supplier selection. They have used total cost function (including yearly order costs, yearly maintenance costs, and yearly purchasing costs), quality function and service function to solve the problem in fuzzy environment.

Guneri, A. et al (2009) presented a fuzzy-LP approach and used fuzzy set theory and TOPSIS to solve the problem. First the decision-makers rate suppliers through a fuzzy TOPSIS process and different orders are allocated to different suppliers.

Wang et al (2005) have developed a decision-based methodology for supply chain design that a plant manager can use to select suppliers. This methodology was derived from the techniques of analytical hierarchy process (AHP) and pre-emptive goal programming.

Supplier selection problem is not just an academic issue. Several supplier selection methods have been identified and widely applied in the industry. Boeing, for instance, adopts a Preferred Supplier Certification program – a rigorous supplier selection process helping to foster long-term relationships with a core group of high-quality, low-cost, on-time suppliers. Boeing grades performance quarterly, providing a report card that becomes a tool for improvement and ongoing dialogue in areas of common interest. This program enables Boeing to work closely with its supplier partners by helping them eliminate waste in their own processes (www.boeing.com).

In this paper, we extended to the concept of fuzzy AHP and fuzzy TOPSIS to develop a methodology for solving supplier selection problems in fuzzy environment for an optical industry. Considering the fuzziness in the decision data and group decision-making process, linguistic variables are used to assess the weights of all criteria and the ratings of each supplier with respect to each criterion. We can convert

the decision matrix into a fuzzy decision matrix and construct a weighted-normalized fuzzy decision matrix once the decision-makers' fuzzy ratings have been pooled. According to the concept of TOPSIS, we define the fuzzy positive ideal solution (FPIS) and the fuzzy negative ideal solution (FNIS). Then, a vertex method is applied to calculate the distance between two fuzzy ratings. Using the vertex method, we can calculate the distance of each supplier from FPIS and FNIS, respectively. Finally, a closeness coefficient of each supplier is defined to determine the ranking order of all suppliers. The higher value of closeness coefficient indicates that a supplier is closer to FPIS and farther from FNIS simultaneously. Then, we apply linear programming in order to take more factors in to consideration. These factors affect supplier selection process severely and industries need to take all of them in to account. The maximum demand in a time interval for supplying material or services, the quality of suppliers' products in terms of rate of defects in previous orders, the production capacities of suppliers are such factors that are important for industries to enable them to make appropriate decision. Therefore, the presented model here is a combination of fuzzy AHP, fuzzy TOPSIS and Linear Programming; however there are some unique advantages as follows:

- Take different background of decision makers such as their educational level, job history and organizational rank in to consideration by pair wise comparison of committee members by senior manager. In fact the committee members comes from different departments of organization with different experiences and background and it is desirable for senior manager to consider these differences.
- Pay attention to interests and concerns of practitioners during implementation of the model as a decision software which integrated in whole information system of a local company. The software is now commercially available.
- Pair wise comparison of criteria linguistically instead of setting an importance level. This makes the judgment more precise because it is more convenient for human to judge the objects pair wise.

2. Definitions

2.1. *Fuzzy number*

Fuzzy concept introduced by Zadeh[27] to overcome the vagueness of information. A positive triangular fuzzy number (TFN) defined as $\tilde{\boldsymbol{A}} = (\boldsymbol{l}, \boldsymbol{m}, \boldsymbol{u})$ shown in Figure 1 and the membership function defined as Eq. (2.1).

$$\mu_A(x) = \begin{cases} \frac{x-l}{m-l} \quad if \;\; l \le x \le m \\ \frac{u-x}{u-m} if \;\; m \le x \le u \\ 0 \qquad\qquad Otherwise \end{cases} \quad (2.1)$$

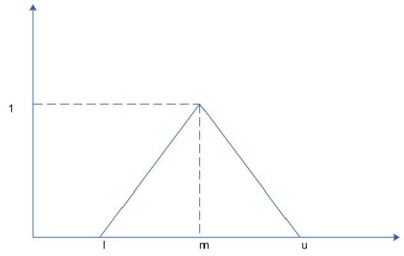

Figure 1. Triangular fuzzy number

2.2. *Fuzzy matrix*

$\tilde{F}$ is a fuzzy matrix if at least one element is fuzzy number.[5]

2.3. *Fuzzy distance*

The distance between two fuzzy numbers $\tilde{A} = (l_1, m_1, u_1)$ and $\tilde{B} = (l_2, m_2, u_2)$ is calculated by three-dimensional Euclidean distance:

$$d(\tilde{A}, \tilde{B}) = \sqrt{\frac{1}{3}[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2} \quad (2.2)$$

2.4. *Operation on fuzzy numbers*

Let $\tilde{A}$ and $\tilde{B}$ be two TFN given by $\tilde{A} = (l_1, m_1, u_1)$ and $\tilde{B} = (l_2, m_2, u_2)$ respectively and p is a real positive number. Some algebraic operations of TFN are as follows:

$$\tilde{A} \oplus \tilde{B} = (l_1 + l_2,\ m_1 + m_2, u_1 + u_2) \quad (2.3)$$

$$\tilde{A} \otimes \tilde{B} = (l_1 l_2, m_1 m_2, u_1 u_2) \quad (2.4)$$

$$\tilde{A} - \tilde{B} = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \;\; for\; l > 0, m > 0, u > 0 \quad (2.5)$$

$$p \otimes \tilde{B} = (pl_1, pm_1, pu_1) \;\; for\; l > 0, m > 0, u > 0 \quad (2.6)$$

$$\tilde{A} \oslash \tilde{B} = (l_1/u_2\ , m_1/m_2\ , u_1/l_2\ ) \quad (2.7)$$

$$\tilde{A}^{-1} = (1/u\_1\ , 1/m\_1\ , 1/l\_1\ )\ for\; l > 0, m > 0, u > 0 \quad (2.8)$$

2.5. *Linguistic Variables*

Linguistic variables are variables whose values are words or sentences in a natural or artificial language. In other words, they are variables with lingual expression as their values (Hsieh et al, 2004). For instance if the weather is concerned then the linguistic variable set could be {very hot, hot, moderate, cold,

and very cold}. In the presented model of this paper, decision makers use linguistic variables. They use linguistic variable shown in Figure 2 and Table 2 to evaluate the importance of criteria. The linguistic variable for rating suppliers with respect to each criterion is showed in Figure 3 and Table. 3.

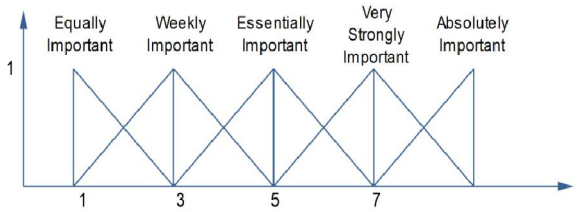

Figure 2. Membership functions of the linguistics variables for criteria comparisons

Table 2. Memberships function of the linguistic scale for pairwise comparison of criteria.

Fuzzy Number	Linguistic Scales	TFN	Reciprocal of a TFN
$\tilde{9}$	Absolutely important	(7,9,9)	(1/9,1/9.1/7)
$\tilde{7}$	Very strongly important	(5,7,9)	(1/9,1/7,1/5)
$\tilde{5}$	Essentially important	(3,5,7)	(1/7,1/5.1/3)
$\tilde{3}$	Weakly important	(1,3,5)	(1/5,1/3,1)
$\tilde{1}$	Equally important	(1,1,3)	(1/3,1,1)
$\tilde{2},\tilde{4},\tilde{6},\tilde{8}$	Intermediate value between two adjacent judgments		

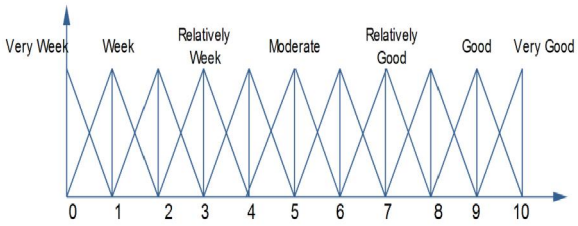

Figure 3. Membership functions of the seven levels of linguistic variables for rating alternatives

For example, "Essentially Important" can be presented as (3,5,7) and its membership function is:

$$\mu_A(x) = \begin{cases} \frac{x-3}{5-3} & if\ 3 \le x \le 5 \\ \frac{x-7}{5-7} & if\ 5 \le x \le 7 \\ 0 & otherwise \end{cases} \qquad (2.9)$$

Table. 3. Membership functions of the seven levels of linguistic variables for rating alternatives

Fuzzy Number	*Linguistic Scales*	*TFN*
$\tilde{10}$	*Very Good*	*(9,10,10)*
$\tilde{9}$	*Good*	*(8,9,10)*
$\tilde{7}$	*Relatively Good*	*(6,7,8)*
$\tilde{5}$	*Moderate*	*(4,5,6)*
$\tilde{3}$	*Relatively Week*	*(2,3,4)*
$\tilde{1}$	*Week*	*(0,1,2)*
$\tilde{0}$	*Very Week*	*(0,0,1)*
$\tilde{2},\tilde{4},\tilde{6},\tilde{8}$	*Intermediate value between two adjacent judgments*	

2.6. *Fuzzy Analytic Hierarchical Process*

AHP introduced by Saaty (1980) allows for the application of data, experience, insight, and intuition in a logical and thorough way. AHP enables decision-makers to derive ratio scale priorities or weights as opposed to arbitrarily assigning them. In so doing, AHP not only supports decision-makers by enabling them to structure complexity and exercise judgment, but also allows them to incorporate both objective and subjective considerations in the decision process (Forman, 1983). There are many benefits to using the AHP approach. An important advantage is its simplicity.

The AHP can also accommodate uncertain and subjective information. Another advantage is that the AHP can measure the degree to which a manager's judgments are consistent. Specific (potential) disadvantages of AHP include of inconsistency of the decision maker's judgments and rank reversal (Ross, 1994). In addition, ranking, scoring and AHP methods do not apply to problems having resource feasibility, optimization requirements or project interdependence property constraints (Lee et al, 2001).

Furthermore, the AHP method does not take into account the uncertainty associated with the mapping while the AHP's subjective judgment, selection and preference of decision-makers have great influence on the success of the method (Cheng et al, 1999). Decision-makers usually find that it is more accurate to give interval judgments than fixed value judgments. This is because usually he/she is unable to make his/her preference explicitly about the fuzzy nature of the comparison process (Kahraman et al, 2003). Therefore based on fuzzy paradigm introduced by Zadeh (1965), Fuzzy AHP is used in which local and global priorities from fuzzy preference ratios are derived.

In this paper, we derive fuzzy weight of pair-wise matrix elements by calculating the eigenvalues. Therefore, for each row of pair-wise matrix following formula is obtained:

$S_k = \sum_{j=1}^{n} M_{kl} \times \left[\sum_{i=1}^{m}\sum_{j=1}^{n} M_{ij}\right]^{-1}$ (2.10)

where M is triangular fuzzy number and k, i and j represent matrix row, suppliers and criteria respectively. Suppose we need to calculate the weights of three criteria from following pair-wise comparison matrix:

$$\begin{array}{c} \\ C_1 \\ C_2 \\ C_3 \end{array} \begin{array}{c} \begin{array}{ccc} C_1 & C_2 & C_3 \end{array} \\ \begin{pmatrix} (1,1,1) & (1.2.3) & (2,3,4) \\ (1/3,1/2,1) & (1,1,1) & (3,5,6) \\ (1/4,1/3,1/2) & (1/6,1/5,1/3) & (1,1,1) \end{pmatrix} \end{array}$$

First, we calculate the summation of each row as follows:

$$(1,1,1) + (1,2,3) + (2,3,4) = (4,5,6)$$
$$(1/3,1/2,1) + (1,1,1) + (3,5,6) = (4.3,6.5,8)$$
$$(0.25,0.33,0.50) + (0.17,0.20,0.33) = (1.42,1.53,1.83)$$

Now, the summation of this new column is obtained: (16.83,14.03,17.83)

Then, each element of one column matrix is divided by column summation:

$$(4/17.83,6/14.03,8/16.83)$$
$$(4.33/17.83,6.5/14.03,8/16.83) \quad \text{or}$$
$$(1.42/17.83,1.53/14.03,1.83/16.83)$$

$$\begin{array}{c} C_1 \\ C_2 \\ C_3 \end{array} \begin{pmatrix} (0.224,0.428,0.475) \\ (0.242,0.463,0.475) \\ (0.079,0.109,0.109) \end{pmatrix}$$

3. Proposed Model

Step 1: We suppose a virtual decision-making committee with k members who intend to rank i suppliers with respect to j criteria. To calculate the members' weight, the proposed method by Saaty (1980) is used:

$$W = \lim_{K \to \infty} \frac{DM^{k} . e}{e^{T} . DM^{k} . e} \qquad (3.1)$$

in which $e^T=(1,1,1,...,1)$ and DM is comparison matrix of decision-makers. When the difference between DM_k and DM_{k+1} can be neglected the computation is stopped and the data stored in a weight vector:

$$D = (D_1, D_2, ..., D_k) \qquad (3.2)$$

Step 2: Each member assess the importance of criteria in a pair comparison matrix linguistically. Then the fuzzy numbers are substituted to their equivalent linguistic variables by the scale indicated in Figure 2 and Eq. 3.2 is applied. Suppose the importance of $j=1,...,n$ criteria assessed by $p=1,...,k$ decision makers as such indicated in Table 4.

Table 4. The weight of n criteria assessed by k decision makers

C_n / D_p	D_1	D_2	.....	D_k
C_1	w_{11}	w_{12}	.....	w_{1k}
C_2	w_{21}	w_{22}	.....	w_{2k}
.	.	.		.
.	.	.		.
C_n	w_{j1}	w_{j1}	.....	w_{jk}

in which w_{jk} is a triangular fuzzy number:

$$\tilde{w}_{jk} = (w_1, w_2, w_3) \qquad (3.3)$$

In order to aggregate fuzzy weights of each criterion, we use following method (Chen et al, 2006).

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}) \qquad (3.4)$$

where

$$w_{j1} = \min_k \{w_{jk1}\} \quad ,$$
$$w_{j2} = \frac{1}{k}\sum_{1}^{k} w_{jk2} \quad , \qquad (3.5)$$
$$w_{j3} = \max_k \{w_{jk3}\}$$

Step 3: Now, each member rates selected suppliers with respect to criteria which indicated in Table 5.

Table 5. Rating of m alternatives by k decision makers for n criteria

Criteria	Supplier	Decision Makers			
		D_1	D_2	.....	D_k
C_1	S_1	r_{111}	r_{112}		r_{11k}
	S_2	r_{121}	r_{122}		r_{12k}
	...	....	....	.....	....
	S_m	r_{1m1}	r_{1m2}	...	r_{1mk}
C_2	S_1	r_{211}	r_{212}		r_{21k}
	S_2	r_{221}	r_{222}	.....	r_{22k}
	...	.....	.....	...	....
	S_m	r_{2m1}	r_{2m2}		r_{2mk}
.	.	.	.		.
.	.	.	.	.....	.
.	.	.	.	...	.
C_n	S_1	r_{n11}	r_{n12}		r_{n1k}
	S_2	r_{n21}	r_{n22}	.....	r_{n2k}
	...	.....	.....	...	.....
	S_m	r_{nm1}	r_{nm2}		r_{nmk}

where r_{jip} is a fuzzy triangular number:

$$\tilde{r}_{jip} = (a_{nmk}, b_{nmk}, c_{nmk}) \qquad (3.6)$$

The aggregate fuzzy rating of suppliers on various criteria can be calculated as follows:

$$\tilde{r}_{ji} = (a_{nm}, b_{nm}, c_{nm}) \qquad (3.7)$$

in which

$$a_{nm} = \min_k \{a_{nmk}\},$$
$$b_{nm} = \frac{1}{k}\sum_{k=1}^{k} b_{nmk},$$
$$c_{nm} = \max_k \{c_{nmk}\} \qquad (3.8)$$

The new table or decision matrix illustrated in Table 6.

Table 6. Fuzzy Decision Matrix

Alternatives	*Criteria*			
	C_1	C_2	…….	C_n
S_1	$\tilde{r}11$	$\tilde{r}_{12}$		$\tilde{r}_{1n}$
S_2	$\tilde{r}_{21}$	$\tilde{r}_{22}$	……..	$\tilde{r}_{2n}$
.	.	.		.
.	.	.		.
S_m	$\tilde{r}_{m1}$	$\tilde{r}_{m2}$	……..	$\tilde{r}_{mn}$

The scale of criteria could be different and to avoid complexity in calculations, the transformation is used to transform different criteria scales in to comparable scales. The set of criteria can be divided into benefit criteria (the larger the rating, the greater the preference) and cost criteria (the smaller the rating, the greater the preference)[8]. The normalized decision matrix can be expressed as

$$\tilde{R} = [\tilde{r}_{ij}]_{m\times n} \qquad (3.9)$$

The criteria itself could be benefits or costs. We denote the set of benefit criteria as B and the set of cost criteria as C. Then

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right), \; c_j^* = \max_i c_{ij}, \; j \in B \qquad (3.10)$$

$$\tilde{r}_{ij} = \left(\frac{a_i^-}{c_{ij}}, \frac{a_i^-}{b_{ij}}, \frac{a_i^-}{a_{ij}}\right), \; a_i^- = \max_i a_{ij}, \; j \in C \qquad (3.11)$$

Step 4: Now weighted normalized decision matrix can be calculated according to the normalized fuzzy decision matrix as:

$$\tilde{V} = [\tilde{v}_{ij}]_{m\times n}, \; i = 1,\ldots,m, \; j = 1,\ldots,n \qquad (3.12)$$

where

$$\tilde{v}_{ij} = r_{ij}\tilde{w}_j \qquad (3.13)$$

Step 5: The fuzzy positive-ideal solution (A^*) and fuzzy negative-ideal solution (A^-) can be defined as

$$A^*(\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_n^*), \; A^-(\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_n^-) \qquad (3.14)$$

where

$$\tilde{v}_j^* = \max\{v_{ij3}\}, \quad \tilde{v}_j^- = \min\{v_{ij1}\} \qquad (3.15)$$

and the distance of each supplier from these two ideal points (A^* and A^-) can be calculated by Euclid's formula:

$$d_i^* = \sqrt{\sum_{j=1}^{n} (\tilde{v}_{ij} - \tilde{v}_j^*)^2} \qquad (3.16)$$

$$d_i^- = \sqrt{\sum_{j=1}^{n} (\tilde{v}_{ij} - \tilde{v}_j^-)^2} \qquad (3.17)$$

The relative closeness of suppliers is defined by closeness coefficient in order to determine the ranking order of suppliers:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \quad i = 1,2,\ldots,m \qquad (3.18)$$

This coefficient represents the distances of suppliers to the ideal points simultaneously. It is obvious that if the supplier reaches to A^* or $S_i = A^*$ then $d_i^* = 0$ and $CC_i = 1$ and if the supplier reaches to A^- or $S_i = A^-$ then $d_i^- = 0$ and $CC_i = 0$. It means when the supplier goes toward A^* or farther from A^- then CC_i goes toward 1. Also if the supplier goes toward A^- or farther from A^* then CC_i goes toward 0.

Descending order of CC_i determine the ranking order of suppliers. However, it is more realistic if the assessment status of suppliers describe by linguistic variables accordance to their closeness coefficient. Therefore, the interval [0, 1] could be divided to sub-division. Five sub-divisions is popular as indicated in Table 7 (Chen et al, 2006).

Table 7. Approval status of ranked alternatives

Closeness Coefficient	*Assessment Status*
$CCi \in [0.0,0.2)$	*Do not recommend*
$CCi \in [0.2,0.4)$	*Recommend with high risk*
$CCi \in [0.4,0.6)$	*Recommend with low risk*
$CCi \in [0.6,0.8)$	*Approved*
$CCi \in [0.8,1.0]$	*Approved and preferred*

Step 6: Having the ranking order of suppliers, we need to allocate the optimum quantity for each supplier according to required criteria such as production capacity, best offer for production of one part, average recorded defect rates, available budget and so on. To do this, we develop a linear

programming in which the obtained closeness coefficients are the LP coefficients and other criteria as the LP constraints.

7. Numerical Example

An optical company intends to outsource a main part of a new designed binocular. Five people from different departments are subjected to assess the six suppliers with respect to five criteria. The criteria are Delivery Capabilities (C_1), Technical Knowledge (C_2), Technical Abilities (C_3), Management Obligation (C_4) and Cooperation History (C_5). Based on pair-wise comparison matrix of decision makers (made by senior manager) and using Eq. (5.10) the weight of committee members are obtained and shown in Table 8.

Table 8. The weight of decision makers

Almasi,	Safaei,	Tajado,	Jalaei,	Irani,
0.2578	0.1627	0.1504	0.178	0.2512

In order to obtain the weight of each criterion, equivalent TFN of linguistic variables replaced and Eq. (2.10) is used. The result for five comparison matrixes is shown in Table 9.

Table 9. Fuzzy weight of criteria evaluated by decision makers

Criteria	Almasi, Saman	Safaei, Saeid	Tajado, Farhad	Jalaei, Iman	Irani, Mina
Delivery Capability	(0.0656,0.2515,0.7738)	(0.1369,0.3233,0.6985)	(0.2441,0.4596,0.7635)	(0.1774,0.3842,0.7874)	(0.1747,0.4069,0.7996)
Technical Knowledge	(0.1356,0.3429,0.8475)	(0.1486,0.3101,0.5903)	(0.1285,0.269,0.5407)	(0.1206,0.2622,0.6245)	(0.1414,0.2866,0.6276)
Technical Abilities	(0.0726,0.1905,0.5527)	(0.1185,0.2362,0.4852)	(0.0986,0.1987,0.4058)	(0.0907,0.2378,0.5159)	(0.0877,0.2182,0.4901)
Management Obligation	(0.0589,0.1539,0.4299)	(0.0466,0.1014,0.2556)	(0.0184,0.0372,0.0992)	(0.0189,0.0343,0.1321)	(0.0279,0.045,0.1771)
Cooperation History	(0.0235,0.0612,0.2039)	(0.0168,0.0289,0.1096)	(0.0248,0.0355,0.135)	(0.028,0.0815,0.2356)	(0.0198,0.0434,0.1206)

In addition, the equivalent TFN of linguistic variables (shown in Figure3) replaced in rating tables of suppliers which evaluated by five decision makers. Also in order to take the weight of decision makers in to consideration, their weight is applied to their assessments of criteria and suppliers. The results are shown in Table 10 and 11.

Table 10. New fuzzy weight of criteria

Criteria	Almasi, Saman	Safaei, Saeid	Tajado, Farhad	Jalaei, Iman	Irani, Mina
Delivery Capability	(0.0169,0.0648,0.1995)	(0.0223,0.0526,0.1136)	(0.0367,0.0691,0.1148)	(0.0316,0.0684,0.1402)	(0.0439,0.1022,0.2009)
Technical Knowledge	(0.035,0.0884,0.2185)	(0.0242,0.0505,0.096)	(0.0193,0.0405,0.0813)	(0.0215,0.0467,0.1112)	(0.0355,0.072,0.1577)
Technical Abilities	(0.0187,0.0491,0.1425)	(0.0193,0.0384,0.0789)	(0.0148,0.0299,0.061)	(0.0161,0.0423,0.0918)	(0.022,0.0548,0.1231)
Management	(0.0152,0.0397,0.1108)	(0.0076,0.0165,0.0416)	(0.0028,0.0056,0.0149)	(0.0034,0.0061,0.0235)	(0.007,0.0113,0.0445)
Cooperation History	(0.0061,0.0158,0.0526)	(0.0027,0.0047,0.0178)	(0.0037,0.0053,0.0203)	(0.005,0.0145,0.0419)	(0.005,0.0109,0.0303)

Table 11. Fuzzy weight of criteria evaluated by decision makers with consideration of their weight

Criteria	Sup	Almasi, Saman	Safaei, Saeid	Tajado, Farhad	Jalaei, Iman	Irani, Mina
Delivery Capability	A1	(0.5156,0.7734,1.0312)	(0.3254,0.4881,0.6508)	(0,0.1504,0.3008)	(0.356,0.534,0.712)	(0.5024,0.7536,1.004)8)
Delivery Capability	A2	(0.5156,0.7734,1.0312)	(0.9762,1.1389,1.3016)	(0.9024,1.0528,1.2032)	(0.712,0.89,1.068)	(1.5072,1.7584,2.0096)
Delivery Capability	A3	(1.0312,1.289,1.5468)	(0.6508,0.8135,0.9762)	(0.3008,0.4512,0.6016)	(0,0.178,0.356)	(0.5024,0.7536,1.0048)
Delivery Capability	A4	(1.0312,1.289,1.5468)	(0.9762,1.1389,1.3016)	(1.2032,1.3536,1.504)	(0.712,0.89,1.068)	(1.5072,1.7584,2.0096)
Delivery Capability	A5	(0.5156,0.7734,1.0312)	(0.6508,0.8135,0.9762)	(0.3008,0.4512,0.6016)	(0.356,0.534,0.712)	(1.0048,1.256,1.5072)
Delivery Capability	A6	(2.3202,2.578,2.578)	(1.4643,1.627,1.627)	(1.3536,1.504,1.504)	(1.068,1.246,1.424)	(2.0096,2.2608,2.512)
Technical Knowledge	A1	(0.5156,0.7734,1.0312)	(0.3254,0.4881,0.6508)	(0.6016,0.752,0.9024)	(0.712,0.89,1.068)	(1.0048,1.256,1.5072)
Technical Knowledge	A2	(1.5468,1.8046,2.0624)	(0.6508,0.8135,0.9762)	(0.9024,1.0528,1.2032)	(1.068,1.246,1.424)	(2.0096,2.2608,2.512)
Technical Knowledge	A3	(0,0.2578,0.5156)	(0,0.1627,0.3254)	(0.3008,0.4512,0.6016)	(0.712,0.89,1.068)	(1.0048,1.256,1.5072)
Technical Knowledge	A4	(1.5468,1.8046,2.0624)	(1.3016,1.4643,1.627)	(0.9024,1.0528,1.2032)	(0.356,0.534,0.712)	(1.5072,1.7584,2.0096)
Technical Knowledge	A5	(0.5156,0.7734,1.0312)	(0.6508,0.8135,0.9762)	(0.3008,0.4512,0.6016)	(0.712,0.89,1.068)	(1.0048,1.256,1.5072)
Technical Knowledge	A6	(2.0624,2.3202,2.578)	(1.4643,1.627,1.627)	(1.2032,1.3536,1.504)	(1.068,1.246,1.424)	(2.0096,2.2608,2.512)
Technical Abilities	A1	(0.5156,0.7734,1.0312)	(0.6508,0.8135,0.9762)	(0,0.1504,0.3008)	(0.356,0.534,0.712)	(0.5024,0.7536,1.0048)
Technical Abilities	A2	(1.0312,1.289,1.5468)	(0.9762,1.1389,1.3016)	(0.9024,1.0528,1.2032)	(1.068,1.246,1.424)	(1.5072,1.7584,2.0096)
Technical Abilities	A3	(1.0312,1.289,1.5468)	(0.3254,0.4881,0.6508)	(0.3008,0.4512,0.6016)	(0.712,0.89,1.068)	(1.0048,1.256,1.5072)
Technical Abilities	A4	(1.5468,1.8046,2.0624)	(0.9762,1.1389,1.3016)	(1.2032,1.3536,1.504)	(1.068,1.246,1.424)	(1.5072,1.7584,2.0096)
Technical Abilities	A5	(0.5156,0.7734,1.0312)	(0.3254,0.4881,0.6508)	(0.6016,0.752,0.9024)	(0.712,0.89,1.068)	(0.5024,0.7536,1.0048)
Technical Abilities	A6	(2.0624,2.3202,2.578)	(1.3016,1.4643,1.627)	(1.2032,1.3536,1.504)	(1.424,1.602,1.78)	(2.0096,2.2608,2.512)
Management Obligat	A1	(1.0312,1.289,1.5468)	(0.3254,0.4881,0.6508)	(0.3008,0.4512,0.6016)	(0.712,0.89,1.068)	(1.5072,1.7584,2.0096)
Management Obligat	A2	(2.0624,2.3202,2.578)	(1.3016,1.4643,1.627)	(0.9024,1.0528,1.2032)	(1.068,1.246,1.424)	(0.5024,0.7536,1.0048)
Management Obligat	A3	(1.0312,1.289,1.5468)	(0,0.1627,0.3254)	(0.3008,0.4512,0.6016)	(0.356,0.534,0.712)	(2.0096,2.2608,2.512)

Management Obligat	A4	(1.5468,1.8046,2.0624)	(0.9762,1.1389,1.3016)	(0.9024,1.0528,1.2032)	(0.712,0.89,1.068)	(1.5072,1.7584,2.0096)
Management Obligat	A5	(1.0312,1.289,1.5468)	(0.3254,0.4881,0.6508)	(0.3008,0.4512,0.6016)	(0.356,0.534,0.712)	(1.0048,1.256,1.5072)
Management Obligat	A6	(2.0624,2.3202,2.578)	(1.4643,1.627,1.627)	(1.2032,1.3536,1.504)	(1.068,1.246,1.424)	(1.5072,1.7584,2.0096)
Cooperation History	A1	(0.5156,0.7734,1.0312)	(0,0,0.1627)	(0,0.1504,0.3008)	(0,0.178,0.356)	(0.5024,0.7536,1.0048)
Cooperation History	A2	(1.0312,1.289,1.5468)	(1.3016,1.4643,1.627)	(1.2032,1.3536,1.504)	(0.712,0.89,1.068)	(1.5072,1.7584,2.0096)
Cooperation History	A3	(0.5156,0.7734,1.0312)	(0.9762,1.1389,1.3016)	(0.6016,0.752,0.9024)	(0.356,0.534,0.712)	(0.5024,0.7536,1.0048)
Cooperation History	A4	(1.5468,1.8046,2.0624)	(0.9762,1.1389,1.3016)	(1.2032,1.3536,1.504)	(1.068,1.246,1.424)	(1.5072,1.7584,2.0096)
Cooperation History	A5	(1.0312,1.289,1.5468)	(0.6508,0.8135,0.9762)	(0.6016,0.752,0.9024)	(0.712,0.89,1.068)	(1.0048,1.256,1.5072)
Cooperation History	A6	(2.0624,2.3202,2.578)	(1.4643,1.627,1.627)	(1.3536,1.504,1.504)	(1.424,1.602,1.78)	(2.0096,2.2608,2.512)

To get aggregated fuzzy weights of each criterion, Eq. (3.5) is used. The result is illustrated in Table. 12.

Table 12. Aggregated fuzzy weights of criteria

Delivery	Capability Technical	Technical Abilities	Management	Cooperation
(0.0169,0.0714,0.2	(0.0193,0.0596,0.2	(0.0148,0.0429,0.1	(0.0028,0.0158,0.11	(0.0027,0.0102,0.0

Also Eq. (3.8) is used to calculate the aggregate fuzzy rating of suppliers on various criteria which illustrated in Table 13.

Table 13. Aggregated fuzzy weights of suppliers

Suppli	Delivery	Technical	Technical	Management	Cooperation
A1	(0,0.5399,1.0312)	(0.3254,0.8319,1.	(0,0.605,1.0312)	(0.3008,0.9753,2.009	(0,0.3711,1.0312
A2	(0.5156,1.1227,2.	(0.6508,1.4355,2.	(0.9024,1.297,2.0	(0.5024,1.3674,2.578	(0.712,1.3511,2.0
A3	(0,0.6971,1.5468)	(0,0.6035,1.5072)	(0.3008,0.8749,1.	(0,0.9395,2.512)	(0.356,0.7904,1.3
A4	(0.712,1.286,2.00	(0.356,1.3228,2.0	(0.9762,1.4603,2.	(0.712,1.3289,2.0624	(0.9762,1.4603,2.
A5	(0.3008,0.7656,1.	(0.3008,0.8368,1.	(0.3254,0.7314,1.	(0.3008,0.8037,1.546	(0.6016,1.0001,1.
A6	(1.068,1.8432,2.5	(1.068,1.7615,2.5	(1.2032,1.8002,2.	(1.068,1.661,2.578)	(1.3536,1.8628,2.

The normalized decision matrix is now obtained using Eq. (3.10) and (3.11) which shown in Table 14. All involved criteria in this project are belongs to benefit sets.

Table 14. Normalized Decision Matrix

Suppli	Delivery	Technical	Technical	Management	Cooperation
A1	(0,0.2094,0.4)	(0.1262,0.3227,0.	(0,0.2347,0.4)	(0.1167,0.3783,0.779	(0,0.1439,0.4)
A2	(0.2,0.4355,0.779	(0.2524,0.5568,0.	(0.35,0.5031,0.77	(0.1949,0.5304,1)	(0.2762,0.5241,0.
A3	(0,0.2704,0.6)	(0,0.2341,0.5846)	(0.1167,0.3394,0.	(0,0.3644,0.9744)	(0.1381,0.3066,0.
A4	(0.2762,0.4988,0.	(0.1381,0.5131,0.	(0.3787,0.5664,0.	(0.2762,0.5155,0.8)	(0.3787,0.5664,0.
A5	(0.1167,0.297,0.5	(0.1167,0.3246,0.	(0.1262,0.2837,0.	(0.1167,0.3117,0.6)	(0.2334,0.3879,0.
A6	(0.4143,0.715,1)	(0.4143,0.6833,1)	(0.4667,0.6983,1)	(0.4143,0.6443,1)	(0.5251,0.7226,1

To calculate the weighted normalized fuzzy decision matrix, Eq. (3.12) and (3.13) are used. The results are shown in Table 15.

Table 15. Weighted normalized decision matrix

Suppli	Delivery	Technical	Technical	Management	Cooperation
A1	(0,0.015,0.0803)	(0.0024,0.0192,0.	(0,0.0101,0.057)	(0.0003,0.006,0.0864	(0,0.0015,0.021)
A2	(0.0034,0.0311,0.	(0.0049,0.0332,0.	(0.0052,0.0216,0.	(0.0005,0.0084,0.110	(0.0008,0.0054,0.
A3	(0,0.0193,0.1205)	(0,0.014,0.1277)	(0.0017,0.0146,0.	(0,0.0058,0.108)	(0.0004,0.0031,0.
A4	(0.0047,0.0356,0.	(0.0027,0.0306,0.	(0.0056,0.0243,0.	(0.0008,0.0082,0.088	(0.001,0.0058,0.0
A5	(0.002,0.0212,0.1	(0.0023,0.0193,0.	(0.0019,0.0122,0.	(0.0003,0.0049,0.066	(0.0006,0.004,0.0
A6	(0.007,0.0511,0.2	(0.008,0.0407,0.2	(0.0069,0.03,0.14	(0.0011,0.0102,0.110	(0.0014,0.0074,0.

Using Eq. (3.14) and (3.15) the fuzzy positive-ideal solution (A^*) and fuzzy negative-ideal solution (A^-) is obtained and the distance of each suppliers from these two ideal points are calculated by Eq. (3.16) and (3.17) which illustrated in Tables 16 and 17.

Table. 16. Suppliers' distance from positive ideal solution

	Delivery	Technical	Technical	Management	Cooperation
d^* A1	0.1727	0.1776	0.1227	0.089	0.0461
d^* A2	0.1525	0.1633	0.1072	0.0869	0.041
d^* A3	0.1631	0.1806	0.1146	0.0881	0.0442
d^* A4	0.1503	0.1671	0.1057	0.0878	0.0407
d^* A5	0.1621	0.1776	0.1207	0.092	0.0429
d^* A6	0.1415	0.1591	0.1017	0.0859	0.0394

Table. 17. Suppliers' distance from negative ideal solution

	Delivery	Technical	Technical	Management	Cooperation
d^- A1	0.0472	0.0746	0.0334	0.05	0.0122
d^- A2	0.0922	0.1244	0.0654	0.0642	0.0239
d^- A3	0.0705	0.0742	0.0501	0.0624	0.0154
d^- A4	0.0928	0.1025	0.0674	0.0514	0.0245
d^- A5	0.0689	0.0746	0.0348	0.0385	0.0183
d^- A6	0.1198	0.1284	0.0842	0.0642	0.0307

In order to determine the ranking order of suppliers, relative closeness of suppliers or closeness coefficient is calculated by Eq. (3.18):

Table 18. Suppliers' rank

Supplier	d*	d-	d* + d-	CC = d- / (d- + d*)	Class	
A6	0.5276	0.4273	0.9549	0.4475	Low	Risk
A2	0.5509	0.3701	0.921	0.4018	Low	Risk
A4	0.5516	0.3386	0.8902	0.3804	High	Risk
A3	0.5906	0.2726	0.8632	0.3158	High	Risk
A5	0.5953	0.2351	0.8304	0.2831	High	Risk
A1	0.6081	0.2174	0.8255	0.2634	High	Risk

Table 18 illustrates final results in which suppliers are ranked. In single outsourcing one supplier can satisfy all the buyer's needs (single sourcing) and the management needs to make only one decision; which supplier is the best. If this is the case, the first supplier in table 18 is the best and he/she is selected. However in second type of multi-sourcing (multiple sourcing), no supplier can satisfy all the buyer's requirements. In such circumstances management wants to split order quantities among suppliers for a variety of reasons including creating a constant environment of competitiveness (Ghodsypour et al, 1998). In this case, we need to go forward and allocate different quantities among them based on more criteria.

For this purpose, based on the results obtained in table 18, we continue the calculation in order to integrate the previous model with linear programming and find the optimum quantity for each suppliers according to other constraints such as their production capacity, their best offer for production of one set of binocular part, their previous average defect rates the available budget. The following data is available in the company:

For the time being, the optical company needs to outsource 2500 sets of the part. These are to be exported abroad. The maximum budget ratified for this project by Planning and Budgeting department is 1,312,500,000 Rials. According to current information in suppliers database, their average defect rate (F), their maximum production capacity in 45 days (C) and their best offer for production of one set (P) in Rials is shown in table 19.:

Table 19- Suppliers' data obtained from optical company database

A_1	A_2	A_3	A_4	A_5	A_6
F_1	F_2	F_3	F_4	F_5	F_6
3%	1.7%	3.5%	1.2%	2%	0.5%
C_1	C_2	C_3	C_4	C_5	C_6
1700	2000	1200	2100	1000	1950
P_1	P_2	P_3	P_4	P_5	P_6
550000	530000	510000	540000	495000	525000

Also the maximum acceptable defect for total order is 2%.

If we donate X as the order quantity, the problem is:

$$Max\ (PV) = 0.2634x_1 + 0.4018x_2 + 0.3158x_3 + 0.3084x_4 + 0.2831x_5 + 0.4475x_6$$

$$Subject\ to:$$

$$x_1 + x_2 + x_3 + x_4 + x_5 + x_6 = 2500$$
$$3x_1 + 1.7x_2 + 3.5x_3 + 1.2x_4 + 2x_5 + 0.5x_6 \le 5000$$
$$55x_1 + 53x_2 + 51x_3 + 54x_4 + 49.5x_5 + 52.5x_6 \le 131250$$
$$x_1 \le 1700$$
$$x_2 \le 2000$$
$$x_3 \le 1200$$
$$x_4 \le 2100$$
$$x_5 \le 1000$$
$$x_6 \le 1950$$
$$x_i \ge 0,\ \ i = 1,2,...,6$$

This linear programming can be solved by Microsoft Excel Solver, Win QSB or by our designed software. The result is shown in table 20:

Table 20- optimum order quantity to selected suppliers

X_1	X_2	X_3	X_4	X_5	X_6
0	471	0	0	79	1950

The results show that supplier A_6 gets maximum order. This supplier has been established long-term cooperation with company and that is why A_6 is the best supplier in single outsourcing approach and gets maximum order in multi-outsourcing.

Maximum Purchasing Value (PV) is obtained as:

Objective Function (Max.)= 1,084,290,000

This is less than ratified budget. It means Planning and Budgeting Department over estimated the required costs. In other words, the company has saved 228,210,000 Rials which shows the benefits of method application.

8. Conclusion

In this paper, we presented a hybrid fuzzy MCDM-LP model for supplier selection. This model incorporates fuzzy AHP, fuzzy TOPSIS and Linear Programming to remove the weakness and enhance the strength of each separate method. In addition, the model enables organizations to take different background of decision makers such as their educational level, job history and organizational rank in to consideration. Furthermore, the model enables organizations to select the best supplier in single outsourcing method or allocate optimum order quantity to selected suppliers in multi-outsourcing approach. In the latter case, different constraints such as suppliers' capacities, product qualities, price, available budget and required demand is considered to split order quantities among suppliers for a variety of reasons including creating a constant environment of competitiveness, cutting costs and foster competition between vendors, using vendor specialization and technical expertise, reducing the risk associated with depending on a single supplier.

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