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A SUPPORT SYSTEM FOR GROUP MULTI CRITERIA DECISION MAKING BASED ON FUZZY AHP APPROACH

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ABSTRACT

This paper is designed to present the process of group multi criteria decision making (MCDM) in an automotive manufacturing company, focusing on the selection of tire raw materials suppliers. The process of selecting suppliers is one of the most critical and challenging endeavors in any supply chain management. This study proposes a two-step evaluation model which integrates fuzzy concepts with AHP model to achieve a more human-like model of MCDM. The goal of making decision, criteria and alternatives are structured into a hierarchy. Linguistic variables are used to evaluate relative importance levels of the developed model. The scores of attributes are presented in trapezoidal and triangular fuzzy numbers. The technique for order performance by similarity to ideal solution (TOPSIS) is adapted to the developed model to determine the results. This is followed by the development of a software using MATLAB for the model. The validity and reliability of the results generated from the developed model are found to be in agreement when compared with previous studies concerning supplier selection.

Keywords: *Decision analysis, MCDM, Fuzzy AHP, TOPSIS, Tire supplier selection.*

1.0 INTRODUCTION

A supply chain is a system which consolidates all sectors from suppliers of raw materials or parts to manufacturing, warehousing and distribution of products to customers. Part of the contribution to the complexity of supply chain is the geographical distribution of outsourcing for cheaper supplies and new markets penetration. In decision making, one of the most widely used methods is Analytical Hierarchy Process (AHP). It is a mathematical theory for decision making and this measurement was introduced by Saaty (1980). It assists decision makers to make effective decision based on its goals, criteria and alternatives. AHP can be applied in decision making which is unstructured, complex and consists of multiple criteria (Saaty, 1986). In AHP, a methodology is created which facilitates the selection of the most acceptable supplier from a group of suppliers. This methodology considers various criteria which include both qualitative and quantitative criteria. Its validity is based on many applications in which the AHP results have been accepted and used by these cognizant decision makers (Saaty, 1994). This method has been used in various areas including performance evaluation, supplier selection, credit scoring, poject management, resource allocation, distribution channel management, inventory management, promotion and recruitment decisions, portfolio management, energy resources planning, technology management, financial planning, budgeting decisions, socio-economic planning, common vote prediction and conflict resolution. AHP is a versatile tool as it can be combined with other types of operations research in order to handle more complex problems (Durán and Aguilo, 2008).

Any industry is bound to face a certain level of complexity with respect to meeting customers' demands while other industries prefer higher delivery service in terms of speed, reliability and flexibility. The complexity of supply chain is aggravated further when the industry relies too much on multi range products and constant-changing new products as a strategy to meet the different segmented market demands. In the automotive industry, such a situation is rampant. The frequent introduction of new models, shorter product lifecycles compounded by fast order-delivery requires a high level of agility and flexibility on the part of the suppliers; thereby, exacerbates the supply chain complexity. A reliable supplier should have certain definitive characteristics. This includes flexibility, comprehensiveness and objectiveness (Stevenson and Spring, 2007; Mithat *et al*., 2011; Beach *et al*., 2000). In today's competitive environment, it is impossible to successfully produce low cost, high quality products without the help of satisfactory vendors (Weber, 1990; Yuhazri *et al.*, 2012). Hence, the right selection of suppliers becomes more complicated. However, with the mounting complexity of supply chain, the selection of suppliers becomes very challenging. Thus, purchasing function for any organization bears increasingly greater responsibilities in the supplier selection process (Chen *et al*., 2006).

Supplier selection decision process is a multi criteria problem whereby the decision process has to consider both qualitative and quantitative criteria (Kahraman *et al*., 2003; Chen *et al*., 2006). In order to make a decision which reflects human thinking, the system needs to be more realistic. For realistic decision making, decision makers prefer to evaluate a criterion with a certain level of tolerance rather than a fixed value judgment (Wang *et al*., 2010). Due to this, fuzzy logic, which is a system that reflects a human-like thinking model, is introduced (Zadeh, 1965). This system describes a matter with a certain degree of characteristic which is also known as membership function. Membership function is a graphical representation which associates with the magnitude of input and unltimately determines an output response. There are different membership functions associated with each input and output response. An integrated approach between Fuzzy Logic and AHP in making decision can create a more realistic decision making model since both tools have their own strength in different approaches (Chen *et al*., 2006; Wang *et al*., 2009). For further realistic results of MCDM, a technique known as Technique for Order Performance by Similarity to Ideal Solution or TOPSIS is integrated with Fuzzy AHP. TOPSIS was developed by Hwang and Yoon (1981). It is based upon the concept that the chosen alternative should have the shortest distance from the positive ideal solution.

After much in depth study and research, it was found that there is no related previous study done on the design of decision support system (DSS) that integrates Fuzzy, AHP and TOPSIS. This motivates the current work to be carried out, focusing on the design of a particular DSS to facilitate decision makers in making an effective decision. It is to be noted here that this work is an extension of Chen, Lin and Huang's work (2006). The remainder of this paper is organised as follows: Section 2 will explain fuzzy concepts and the integration between fuzzy AHP and TOPSIS while Section 3 will show the developed model with several empirical examples of application, and finally, Section 4 will present the conclusions.

2.0 BACKGROUND OF FUZZY CONCEPTS

Fuzzy sets can be simply defined as a set with fuzzy boundaries whereby the values of boundaries are multi-valued unlike the two-valued Boolean logic. In fuzzy theory, fuzzy set *X* of universe *Y* is defined by function $\mu_X(y)$ which is called the membership functions of set *X*. This notation can be expressed as below (Negnevitsky, 2002):

$$\mu_X(y): Y \rightarrow [0,1] \tag{1}$$

Where;

$\mu_X(y) = 1$ if *y* is totally in *X*; $\mu_X(y) = 0$ if *y* is not in *X*; $0 < \mu_X(y) < 1$ if *y* is partly in *X*.

The set above explains the membership (characteristic) functions of *X* which have the values that range from 0 to 1. It allows a wide range of possible values. The value from 0 to 1 in this set represents the degree of membership of element *y* in set *X*. The membership function is commonly illustrated in terms of membership curve. There are several shapes of membership curve such as triangular, trapezoidal, linear, 'S' curve and bell representations (Ordoobadi, 2009). To evaluate and assess the ratings of suppliers and weight of criteria in this study, triangular and trapezoidal fuzzy numbers of linguistic values are applied. Trapezoidal fuzzy numbers can be described as below whereby $\tilde{a} = (a_1, a_2, a_3, a_4)$ (Kaufmann and Gupta, 1991).

$$\mu_{\tilde{n}}(x) = \begin{cases} 0, \; x < a_1 \\ \dfrac{x - a_1}{a_2 - a_1}, \; a_1 \le x \le a_2, \\ 1, \; a_2 \le x \le a_3, \\ \dfrac{x - a_4}{a_3 - a_4}, a_3 \le x \le a_4, \\ 0, x > a_4. \end{cases} \tag{2}$$

From equation (1), if $a_2 = a_3$ then $\tilde{a}$ fuzzy number is now called a triangular fuzzy number. In defining the weights of criteria and comparing the alternatives, a set of pair-wise comparison was developed by Saaty (1980) as part of the steps in AHP. Since the concept of AHP considers only real exact numbers, the set of pair-wise comparison by Saaty has been modified to suit human judgement. The scale of weight and criteria preferences are defined in terms of linguistic variables in fuzzy numbers as presented in Tables 1 and Table 2 (Chen *et al*., 2006). Linguistic variables are used to evaluate and assess the ratings of suppliers and weight of criteria. It is defined as variables with values expressed by words in a natural language (Sun, 2010).

Table 1: Linguistic variables for importancy of the criteria

Linguistic variables	Scale of fuzzy number
Very low (VL)	(0, 0, 0.1, 0.2)
Low (L)	(0.1, 0.2, 0.2, 0.3)
Medium low (ML)	(0.2, 0.3, 0.4, 0.5)
Medium (M)	(0.4, 0.5, 0.5, 0.6)
Medium high (MH)	(0.5, 0.6, 0.7, 0.8)
High (H)	(0.7, 0.8, 0.8, 0.9)
Very high (VH)	(0.8, 0.9, 1.0, 1.0)

Throughout this study, the commonly used algebraic operations for fuzzy numbers are addition and multiplication. The fuzzy operators shown below were adapted from Ordoobadi (2009). Let *A* and *B* be two trapezoidal fuzzy numbers with their parameters shown as below:

$$A = (a_1, a_2, a_3, a_4)\ ,\ B = (b_1, b_2, b_3, b_4)$$

Fuzzy numbers addition is defined by:

$$A + B = (a_1 + b_1, a_2 + b_2, a_3 + b_3, a_4 + b_4) \tag{3}$$

On the other hand, fuzzy numbers multiplication is calculated as shown below:

$$A \times B \approx (a_1 b_1, a_2 b_2, a_3 b_3, a_4 b_4) \tag{4}$$

Table 2: Linguistic variables for performance of the alternatives

Linguistic variables	Scale of fuzzy number
Very poor (VP)	(0, 0, 1, 2)
Poor (P)	(1, 2, 2, 3)
Medium poor (MP)	(2, 3, 4, 5)
Fair (F)	(4, 5, 5, 6)
Medium good (MG)	(5, 6, 7, 8)
Good (G)	(7, 8, 8, 9)
Very good (VG)	(8, 9, 10, 10)

2.1 Fuzzy AHP and TOPSIS

Fuzzy sets have the ability to act towards the logical thinking and behaviour of human brains when faced with impreciseness. In this study, a combination of triangular and trapezoidal fuzzy number of linguistic variables is applied since both of the shapes provide an adequate representation of the expert knowledge besides being easy to understand and commonly used (Negnevitsky, 2002; Ordoobadi, 2009). The usage of triangular fuzzy number is due to their intuitive and computational-efficient representation (Karsak, 2002). However, trapezoidal fuzzy numbers also has its own strength as it is capable in capturing the most-likely situation that involves a great amount of uncertainty (Pan, 2008). Thus, the integration between both representations has been developed to create a more accurate and practical result. The linguistic values of triangular and trapezoidal from Tables 1 and Table 2 are presented graphically as shown in Figures 1(a) and Figure 1(b). This integration makes it more practical and reliable for decision makers because of its human-like thinking capability. This technique for Order Preference by Similarity to Ideal Solution or also better known as TOPSIS was developed by Chen and Hwang (1992) while Hwang and Yoon (1981) ranked the preference order. This method is based on the idea that the best alternative (alternative 1 = Z_1 and alternative 2 = Z_2) should be at the shortest distance from the positive ideal solution and farthest from the negative ideal solution and vice versa, as presented in a vectograph in Figure 2. (Wang *et al*., 2010). However, TOPSIS only considers crisp values, whereas human judgments are usually uncertain and could not be evaluated using fix numbers. In spite to this, fuzzy numbers are used to replace all the crisp values in TOPSIS.

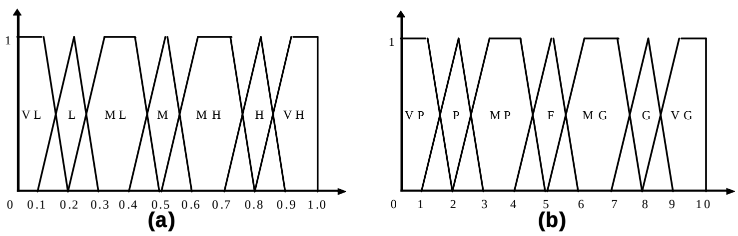


Figure 1: Linguistic variables of **(a)** importance weight for criteria, **(b)** alternatives ratings

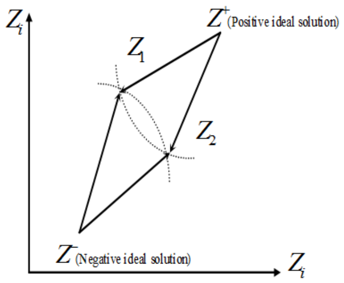


Figure 2: Vectorgraph of TOPSIS

3.0 System Development and Application

In making decisions for supplier selection, it is agreed by De Boer *et al.*, (1998) and Chen *et al.*, (2006) that the decisions made are very often involved by several decision makers. Therefore, the developed model for the current work involves more than one decision maker. The proposed model is not restricted only for the usage in supplier selection. It can also be used in other areas that involve decision making, such as in engineering design, project management or even in daily decision making problem, as long as the decision maker is interested to evaluate the alternatives by applying fuzzy AHP TOPSIS approach.

4.0 System Architecture – Proposed Software

The prototype system was developed by using MATLAB (R2007B). This model involves three decision makers (DM_1, DM_2 and DM_3) with five potential alternatives (S_1, S_2, S_3, S_4 and S_5) and five criteria. The types of criteria below are obtained from a survey in local tire and automotive companies in Malaysia:

(i) Cost (C_1)
(ii) Product quality (C_2)
(iii) Delivery (C_3)
(iv) Supplier background and financial stability (C_4)
(v) Technology and design capabilities (C_5)

The system architecture of the developed model is illustrated in Figure 3. From the figure, it can be seen that the system has three major components which are:

(i) 'A': selection of criteria ranking and supplier's performance
(ii) 'B': interpretation of data
(iii) 'C': results

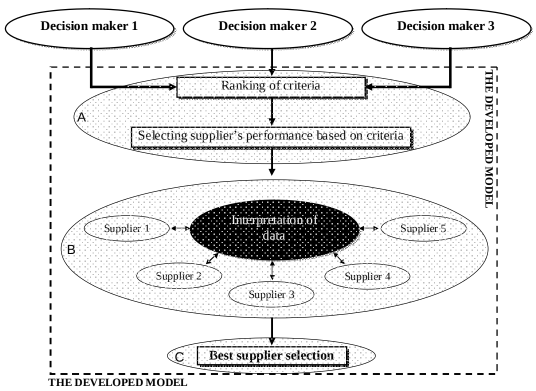
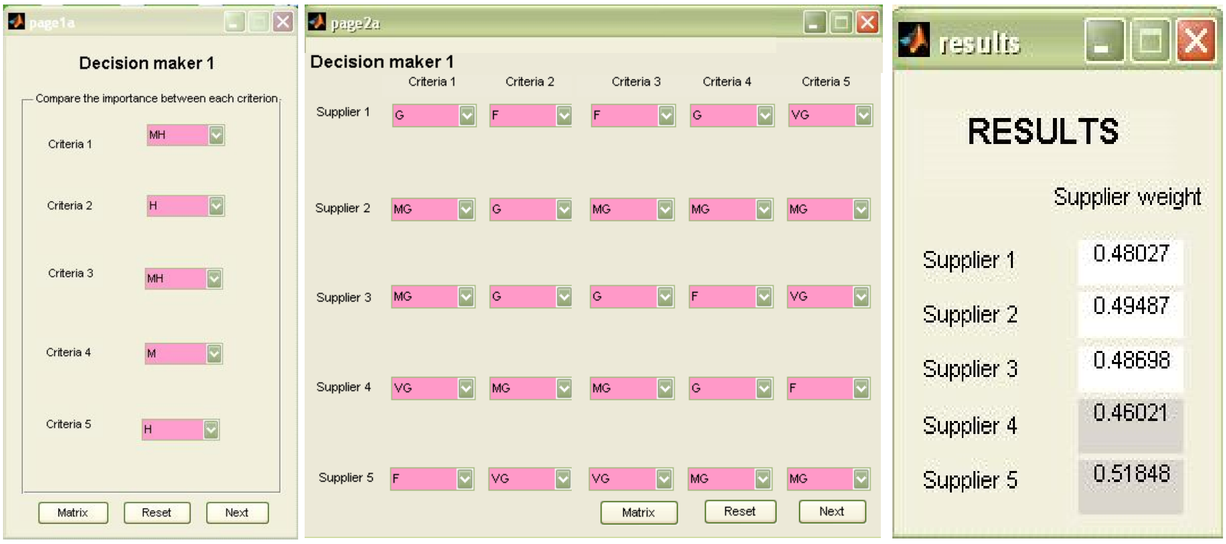


Figure 3: System architecture of the developed model for decision makers in selecting the best supplier

In the first component, (A) decision makers are required to select the ranking of the criteria based on its importance towards the goal. Accordingly, performance of the suppliers based on the criteria is then selected. From Figure 4(a) and Figure 4(4) the decision maker is required to key in the ranking of the criteria and the suppliers' performance with respect to the criteria. Following to this, a drop-down menu of linguistic variables is developed and presented. The acronyms linguistic values from Figure 4(a) and Figure 4(b) are presented in Tables 1 and 2. The above procedures are the same for the remaining two decision makers where their figures are not presented.



(a) (b) (c)

Figure 4: Screenshots of the developed software showing various stages in optimum supplier selection process **(a)** Screenshot for decision maker 1 selecting criteria ranking, **(b)** Screenshot for decision maker 1 selecting supplier performance based on criteria, **(c)** Screenshot of the results for optimum supplier selection.

In the second component (B), the interpretation of data takes place and the data is processed in the following steps:

(i) Aggregate the ranking of criteria and suppliers' performance
(ii) Normalise the fuzzy decision matrix
(iii) Weighted normalize the fuzzy decision matrix
(iv) Distance to positive and negative ideal solution

After the selection of criteria ranking and suppliers' performance, these data are then aggregated to derive fuzzy weights from group evaluation. The evaluators' decisions are then consolidated. In the aggregation process, the suppliers' performance is evaluated by k decision makers with respect to the criteria as the following:

$$\tilde{x}_{ijk} = (a_{ijk}, b_{ijk}, c_{ijk}, d_{ijk})$$

The representation of $\tilde{x}_{ijk}$ can be observed in Table 3. This expression can then be aggregated as shown in equation (5).

Table 3: Suppliers' performance evaluation

	DM-1					DM-2					DM-3				
	C-1	**C-2**	**C-3**	**C-4**	**C-5**	**C-1**	**C-2**	**C-3**	**C-4**	**C-5**	**C-1**	**C-2**	**C-3**	**C-4**	**C-5**
S-1	G	F	F	G	VG	G	VG	MG	MG	MG	G	F	F	VG	G
S-2	MG	G	MG	MG	MG	MG	G	MG	VG	VG	VG	MG	G	VG	MG
S-3	MG	G	G	F	VG	G	G	F	MG	VG	VG	G	VG	F	MG
S-4	VG	MG	MG	G	F	VG	F	VG	VG	MG	MG	MG	F	MG	MG
S-5	F	VG	VG	MG	MG	F	VG	VG	MG	G	G	VG	G	VG	VG

Note: C=criteria, S=supplier, DM=decision maker, VG=very good, G=good, MG=medium good, F=fair

$$\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}, d_{ij}) \tag{5}$$

where;

$$a_{ij} = \min_k \{a_{ijk}\}, \quad b_{ij} = \frac{1}{k}\sum_{k=1}^{k} b_{ijk}, \quad c_{ij} = \frac{1}{k}\sum_{k=1}^{k} c_{ijk}, \quad d_{ij} = \max_k \{d_{ijk}\}$$

As mentioned earlier, there are two values that need to be evaluated by decision makers. Hence, another item that needs to be aggregated to obtain a single representative value is the criteria ranking or also known as criteria weights where; $\tilde{w}_{jk} = (w_{j1k}, w_{jk2}, w_{jk3}, w_{jk4})$ and the criteria ranking evaluation is presented in Table 4. The aggregated criteria ranking is then calculated as follows:

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}, w_{j4}) \tag{6}$$

where;

$$w_{j1} = \min_k \{w_{jk1}\},\quad w_{j2} = \frac{1}{k}\sum_{k=1}^{k} w_{jk2},\quad w_{j3} = \frac{1}{k}\sum_{k=1}^{k} w_{jk3},\quad w_{j4} = \max_k \{w_{jk4}\}$$

Table 4: Criteria ranking evaluation

	DM-1	DM-2	DM-3
C-1	MH	H	VH
C-2	H	M	M
C-3	MH	MH	H
C-4	M	VH	MH
C-5	H	VH	VH

Note: C=criteria, DM=decision maker, VH=very high, H=high, MH=medium high, M=medium.

The example of aggregated criteria ranking of the above is displayed in Table 5. After the process of aggregation has been completed, the fuzzy decision matrix will be normalised. This matrix is denoted by $\tilde{R}$ as follows:

$$\tilde{R} = [\tilde{r}_{ij}]_{mxn}, i = 1,2,...m,\ j = 1,2,...n \tag{7}$$

where;

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{d_j^+}, \frac{b_{ij}}{d_j^+}, \frac{c_{ij}}{d_j^+}, \frac{d_{ij}}{d_j^+}\right),\quad d_j^+ = \max_i d_{ij}^+$$

Table 5: Aggregated criteria ranking

	w_{j1}	w_{j2}	w_{j3}	w_{j4}
C-1	0.66667	0.76667	0.83333	0.90000
C-2	0.50000	0.60000	0.60000	0.70000
C-3	0.56667	0.66667	0.73333	0.83333
C-4	0.56667	0.66667	0.73333	0.80000
C-5	0.76667	0.86667	0.93333	0.96667

Note: C=criteria

The weighted normalized decision matrix is shown in following matrix $\tilde{V}$;

$$\tilde{V} = [\tilde{v}_{ij}]_{mxn}, i = 1,2,...m,\ j = 1,2,...n \tag{8}$$

where;

$$\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j$$

Generally, $\tilde{v}_{ij}$ is a product of the normalised fuzzy decision matrix and criteria ranking matrix. Once the weighted normalised matrix is obtained, the ranking procedure using TOPSIS can now begin. Since TOPSIS approach is more towards the ideal solution, the next thing to do is to determine the fuzzy positive ideal solution (FPIS, A^+) and fuzzy negative ideal solution (FNIS, A^-). In order to calculate trapezoidal FPIS and FNIS, equation 9 is used. As for the calculation of triangular FPIS and FNIS, equation 10 is used. The purpose of this calculation is to transform aggregated fuzzy rating into crisp value. This method is called the vertex method (Chen, 2000).

$$d_v(\tilde{x},\tilde{y}) = \sqrt{\frac{1}{4}[(x_1-y_1)^2+(x_2-y_2)^2+(x_3-y_3)^2+(x_4-y_4)^2]} \tag{9}$$

$$d_v(\tilde{x},\tilde{y}) = \sqrt{\frac{1}{3}[(x_1-y_1)^2+(x_2-y_2)^2+(x_3-y_3)^2} \tag{10}$$

The best level of solution denoted by A^{+} and the worst level of solution denoted by A^{-} are defined as below:

$$A^{+} = (\tilde{v}_1^{+}, \tilde{v}_2^{+}, \ldots \tilde{v}_n^{+}) \tag{11}$$

$$A^{-} = (\tilde{v}_1^{-}, \tilde{v}_2^{-}, \ldots \tilde{v}_n^{-}) \tag{12}$$

where;
$\tilde{v}_j^{+} = \max_i\{v_{ij4}\}$, $\tilde{v}_j^{-} = \min_i\{v_{ij1}\}$

The distances (d_i^{+} and d_i^{-}) between suppliers from A^{+} and A^{-} can be achieved by the area compensation method and they are shown in equations 13 and 14.

$$d_i^{+} = \sum_{j=1}^{n} d_v(\tilde{v}_{ij,} \tilde{v}_j^{+}), i = 1,2,\ldots m \tag{13}$$

$$d_i^{-} = \sum_{j=1}^{n} d_v(\tilde{v}_{ij,} \tilde{v}_j^{-}), i = 1,2,\ldots m \tag{14}$$

Finally, the closeness coefficient is calculated by using equation 15 in order to determine the ranking of the alternatives. The highest, C_i is the nearest in its distance from FPIS, which means that the particular supplier is the preferable one.

$$C_i = \frac{d_i^{-}}{d_i^{+} + d_i^{-}}, i = 1,2,\ldots m \tag{15}$$

Component 'C' is the final major component of the proposed model that aids in obtaining the best supplier according to the desired criteria. Subsequently, data from Tables 3 and 4 are inserted in the developed model, [c.f. Figure 4(c)], which is the final outcome of results. From Figure 4(c), supplier 5 achieved the highest closeness coefficient which is 0.51848. However, it is to be noted here that the difference between supplier 5 and 2 is small and that indicates that these two suppliers are indeed very competitive. The less preferable supplier is supplier 4 with the score of 0.46021.

In order to test the reliability of the developed model of the current work, three selected models for comparison purposes have been evaluated. Input values from a study done by Ordoobadi (2009) which studied on the development of a supplier selection model using fuzzy logic are selected and keyed in into the proposed model. The results are presented in Table 6. From Table 6, the supplier ranking shown by the proposed model is similar to the previous study conducted by Ordoobadi (2009).

Table 6: The developed model vs. Ordoobadi's model

	The developed model		**Oordobadi's model**	
	Crisp value	Rank	Crisp value	Rank
Supplier A	0.35266	3	13.50	3
Supplier B	0.39592	1	15.78	1
Supplier C	0.37811	2	14.44	2

Another study on performance evaluation model by integrating fuzzy AHP and fuzzy TOPSIS methods was done by Sun (2010) who also adopted the developed model and the corresponding results for supplier selection ranking, and his results are displayed in Table 7. One can see that similar supplier ranking is achieved for both models.

Table 7: The developed model vs. Sun's model

	The developed model		Sun's model	
	Crisp value	Rank	Crisp value	Rank
Supplier A	0.5237	1	0.803	1
Supplier B	0.4741	2	0.746	2
Supplier C	0.4564	3	0.726	3
Supplier D	0.3537	4	0.601	4

To further explore the effectiveness of the developed model in producing reliable results for supplier selection ranking, the work on the development and evaluation of five fuzzy multi attribute decision making methods by Triantaphyllou and Lin (1996) was incorporated into the developed model and its results are shown in Table 8.

Table 8: The developed model vs. Triantaphyllou's model

	The developed model		Triantaphyllou's model	
	Crisp value	Rank	Fuzzy value	Rank
Supplier A	0.2319	2	(0.04, 0.42, 5.83)	2
Supplier B	0.2038	3	(0.01, 0.21, 3.99)	3
Supplier C	0.3516	1	(0.06, 0.79, 10.42)	1

Interestingly, an exact match is noted for the three supplier selection ranking. Hence, the supplier ranking assessment from the developed model is found to be equally robust in the process of selecting the best supplier.

5.0 CONCLUSIONS

In decision making problems, the use of linguistic variables in evaluating criteria is highly beneficial especially when the values cannot be expressed using crisp values of numerical numbers. This is the main reason why fuzzy AHP is applied in the decision making process. However, fuzzy AHP requires a lot of time-consuming calculations (Durán and Aguilo, 2008) and, the calculations are tedious whenever it involves more than one single matrix. The more the number of criteria and alternatives are, the bigger the matrix will be. In this matter, software aid becomes a necessity for decision makers who wish to carry out fuzzy AHP TOPSIS in their decision-making. It can indirectly ease the process in decision making. For the current study, the proposed model has been tested with the past studies and the outcome of supplier selection process is comparatively favorable to the developed model. Hence it can be said that the developed model is reliable in the supplier selection process.

REFERENCES

[1] Beach, R., Muhlemann, A.P., Price, D.H.R., Paterson, A. and Shar, J.A. (2000): A Review of Manufacturing Flexibility. *European Journal of Operational Research*, Vol.122, No.1, pp.41-57.

[2] Chen, T.C. (2000): Extensions of the TOPSIS for Group Decision-Making under Fuzzy Environment, *Fuzzy Set and Systems,* Vo.114, pp.1-9.

[3] Chen, C.T., Lin, C.T. and Huang, S.F. (2006): A Fuzzy Approach for Supplier Evaluation and Selection in Supply Chain Management. *International Journal of Production Economics,* Vol.102, pp.289-301.

[4] Chen, S.J. and Hwang, C.L. (1992): *Fuzzy Multiple Attribute Decision Making: Methods And Applications*. Berlin: Springer.

[5] Boer, D.L., Wegen V.D.L. and Telgen, J. (1998): Outranking Methods in Support of Supplier Selection. *European Journal of Purchasing & Supply Management,* Vol.4, pp.109-118.

[6] Durán, O. and Aguilo, J. (2008): Computer-Aided Machine-Tool Selection Based On A Fuzzy-AHP Approach. *Expert Systems with Applications,* Vol.34, pp.1787-1794.

[7] Hwang, C.L. and Yoon, K. (1981): *Multiple Attribute Decision Making- Methods And Applications*. Heidelberg: Springer-Verlag.

[8] Kahraman, C., Cebeci, U. and Ulukan, Z. (2003): Multi-Criteria Supplier Selection Using Fuzzy AHP. *Logistics Information Management*, Vol.16, pp.382-394.

[9] Karsak, E.E. (2002): Distance-Based Fuzzy MCDM Approach For Evaluating Flexible Manufacturing System Alternatives. *International Journal of Production Research,* Vol.40, No.13, pp.3167-3181.

[10] Kaufmann, A. and Gupta, M.M. (1991): *Introduction to Fuzzy Arithmetic: Theory and Applications*. New York: Van Nostrand Reinhold.

[11] Mithat., Cüneyt., et al. (2011): A Combined Methodology for Supplier Selection and Performance Evaluation. *Expert Systems with Applications* Vol.38, No.3, pp.2741-2751.

[12] Negnevitsky, M. (2002): *Artificial Intelligence: A Guide To Intelligent Systems.* England: Pearson Education Limited.
[13] Ordoobadi, S.M. (2009): Development Of A Supplier Selection Model Using Fuzzy Logic. *Supply Chain Management-an International Journal,* Vol.4, pp.314-327.
[14] Pan, N.F. (2008): Fuzzy AHP Approach For Selecting The Suitable Bridge Construction Method. *Automation in Construction,* Vol.17, pp.958-965.
[15] Saaty, T.L. (1980): *The Analytical Hierarchy Process*. New York: McGrawHill.
[16] Saaty,T.L. (1986): Axiomatic Foundation Of The Analytical Hierarchy Process. *Management Science,* Vol.32, No.7, pp.841-855.
[17] Saaty, T.L. (1994): Highlights and Critical Points in the Theory and Application of the Analytic Hierarchy Process. *European Journal of Operational Research*, Vol.74, pp.426-447.
[18] Stevenson, M. and Spring, M. (2007): Flexibility From A Supply Chain Perspective: Definition And Review. *International Journal of Operations & Production Management* Vol.27, No.7, pp.685-713.
[19] Sun, C.C. (2010): A Performance Evaluation Model By Integrating Fuzzy AHP And Fuzzy TOPSIS Methods. *Expert Systems with Applications,* Vol.37, pp.7745-7754.
[20] Triantaphyllou, E. and Lin, C. (1996): Development and Evaluation of Five Fuzzy Multi-Attribute Decision-Making Methods. *Approximate Reasoning,* Vol.14, No.4, pp.281-310.
[21] Wang, J.W., Cheng, C.H. and Huang, K.C. (2009): Fuzzy Hierarchical TOPSIS For Supplier Selection. *Applied Soft Computing,* Vol.9, pp.377-386.
[22] Wang, J., Fan, K. and Wang, W. (2010): Integration of Fuzzy AHP and FPP with TOPSIS Methodology for Aeroengine Health Assessment. *Expert Systems with Applications,* Vol.37, pp.8516-8526.
[23] Weber, C.A. (1990): Vendor Selection Criteria and Methods. *European Journal of Operational Research* Vol.50, pp.2-18.
[24] Yuhazri, M.Y., Haeryip Sihombing, Yahaya, S.H., Said, M.R., Umar, N., Saijod, L. and Phongsakorn, P.T. (2012): Solid Fuel from Empty Fruit Bunch Fiber and Waste Papers Part 7: Water Absorption Test. *Global Engineers and Technologists Review*, Vol.2, No.7, pp.7-12.
[25] Zadeh, L.A. (1965): Fuzzy Sets. *Information and Control,* Vol.8, pp.338-353.