Journal of Fundamental and Applied Sciences

ISSN 1112-9867

Available online at http://www.jfas.info

Research Article

Special Issue

A HYBRID FUZZY MULTI-CRITERIA DECISION MAKING MODEL FOR GREEN SUPPLIER SELECTION

P. Hashemzahi[1,2], S. N. Musa[1,2,*] and F. Yusof[1,2]

[1]Department of Mechanical Engineering, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia

[2]Centre of Advanced Manufacturing and Material Processing, University of Malaya, 50603 Kuala Lumpur, Malaysia

Published online: 05 October 2017

ABSTRACT

Selecting appropriate suppliers has directly effect on this network efficiency, costs, quality and environmental performance. Hence, supplier selection is significant factor in supply chain success. Supplier selection is a multi-criteria problem, which involve uncertain qualitative and quantitative data. Thus, the aim of this paper is introducing an integrated model for green multiple sourcing in fuzzy environment. This proposed model considers various criteria and sub criteria to evaluate and rank best suppliers. First, fuzzy analytic hierarchy process has been used to find weight of each supplier. Then, a Fuzzy Technique of ranking Preferences by Similarity to the Ideal Solution (TOPSIS) method is developed to rank suppliers and select the appropriate ones. The proposed model helps managers to solve multiple-sourcing problem, reduce purchasing cost, lead time and improve quality and environmental issue.

Keywords: green supplier selection; analytic hierarchy process; multi-objective decision-making; fuzzy TOPSIS.

Author Correspondence, e-mail: nurmaya@um.edu.my

doi: http://dx.doi.org/10.4314/jfas.v9i4s.24

1. INTRODUCTION

In recent competitive business marketing, supply chain management increased industrial groups' competitive capability. Supply chain is managed all step of producing from user order to, raw materials, suppliers, manufacturing process, inventory, logistic and deliver the final product to customer. Fig. 1 is presented supply chain system.

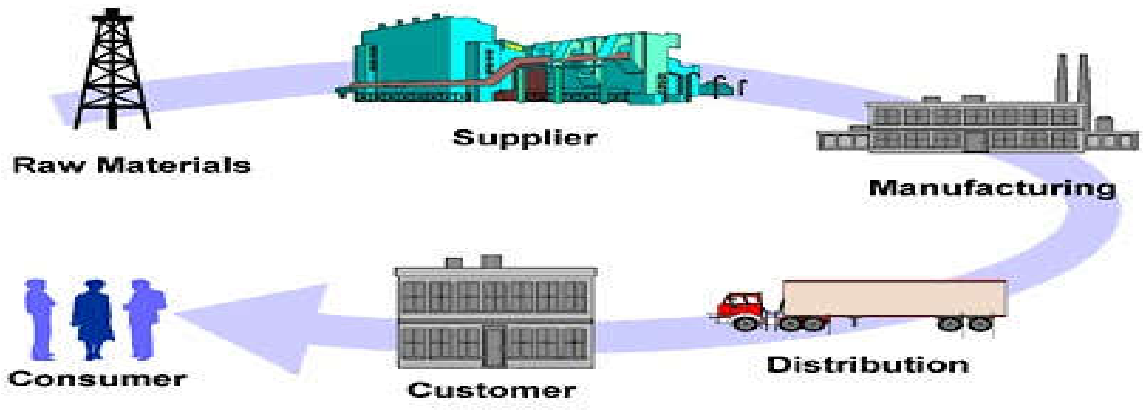

Fig.1. Supply chain system

Supplier selection is critical part of supply chain network, because it has directly effect on final products price, quality, service, lead time and users' satisfaction. Hence, selecting appropriate suppliers is significant issue in whole supply chain performance. Therefore, multiple criteria and sub-criterion involved in supplier selection problems such as cost, quality, service, delivery. Supplier selection is multi criteria decision making (MCDM) problems that includes qualitative and quantitative data [1-3].

Global and government concerns about environmental issue motivated firms to improve their environmental standards of their products. Nowadays, strong economic performance, high quality products and after sale service is not enough for industrial groups success. They cannot refuse environmental aspect, if they want improve their competitive advantages in marketing. Appropriate suppliers will improve whole supply chain network environmental standards.

Many researches have been conducted for solving the issue of supplier selection. Hence, various models have been developed in this area. Most popular single approaches are Analytic hierarchy process (AHP) [4], TOPSIS [5], VIKOR [6], Analytic network process (ANP) [7], Goal programming (GP) [8], multi objective programming [9], Data envelopment analysis

(DEA) [10], Fuzzy set theory (FST) [11-12], etc. The supplier selection problem complexity motivated researcher using integrated models to solving this problem. Most popular integrated approaches are: integrated AHP, DEA and artificial neural network (ANN) [12], integrated AHP and FST [13], integrated AHP and multi-objective programming [14], Integrated ANP and multi-objective programming [15], Integrated fuzzy AHP and fuzzy GP [16], etc.

Many researches have discussed about supplier selection before [17-18], but most of them focus on cost and quality criteria and rarely discuss about lead time and green environmental factors criteria. In traditional decision-making methods, ranking the alternatives were just based on decision maker's opinion with some crisp data, but in real case problems are vague and fuzzy environmental is needed to solve the problem [19-21]. This proposed model aims to help decision makers by using fuzzy AHP and Fuzzy TOPSIS for selecting suppliers. The fuzzy environmental makes model more robust [22], also the environmental factors in this research improve competitive capability of firms.

In the following sections of this paper, we will cover methodology, data gathering, result and discussion and conclusion.

2. INTEGRATED MODEL FOR GREEN SUPPLIER SELECTION

Initially, FAHP is used to determine the weight of the criteria. Then, by applying fuzzy TOPSIS the suppliers are prioritized. Fig. 2 is briefly presented main steps of this paper.

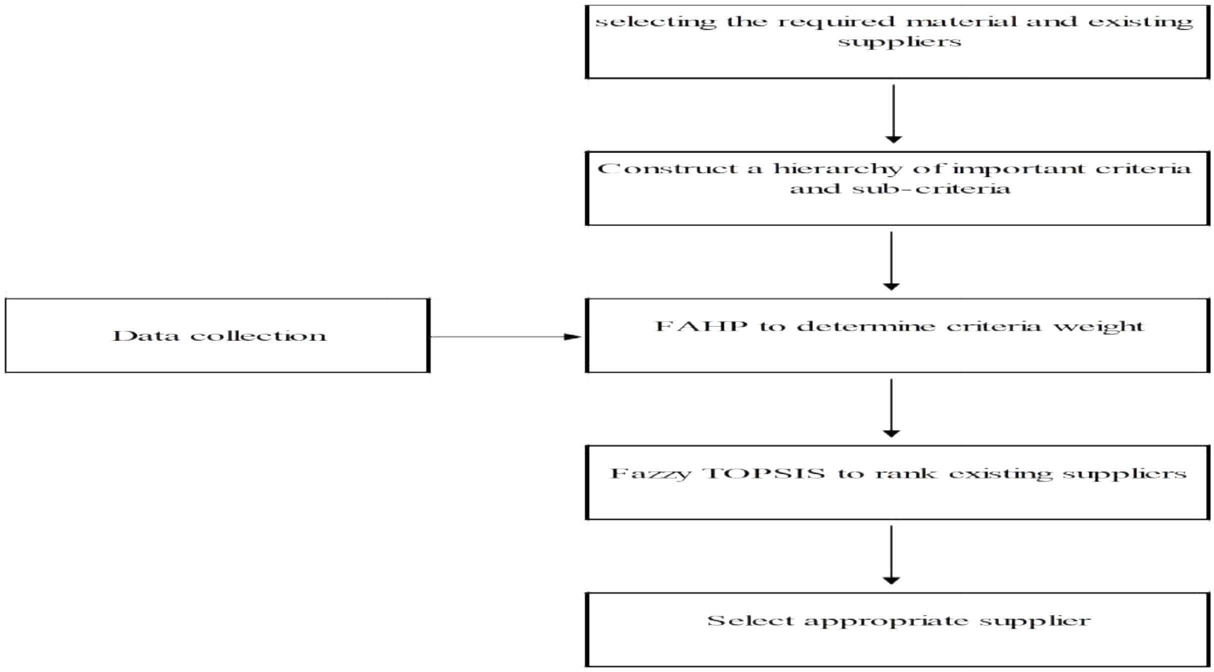

Fig.2. Research framework for supplier selection problem

2.1. Fuzzy Analytic Hierarchy Process

Most of decision-making problems need a fuzzy environment to be solved. Nowadays, using fuzzy logic to solve the problems is so popular [23]. FAHP is a method that will help decision makers to pair-wise different alternatives with several criteria with vague information [4]. In [24] developed a FAHP model to weight of alternatives in MCDM models that is used in this research. The method steps are described as follows:

where M_{gi}^{j}(i = 1, 2, ..., n) and (j = 1, 2, ..., m), it extent analysis details are as following:

i. Initially, the pairwise comparison matrix is built and the value of fuzzy synthetic extent with respect to the i th object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (1)$$

To obtain $\sum_{j=1}^{m} M_{gi}^{j}$ perform the fuzzy addition operation of m extent analysis values for a particular matrix such that:

$$\sum_{j=1}^{m} M_{gi}^{j} = \left[\sum_{j=1}^{m} l_j + \sum_{j=1}^{m} m_j + \sum_{j=1}^{m} u_j\right] \quad (2)$$

And to obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^{j}\right]$ perform the fuzzy addition operation of M_{gi}^{j} (j = 1, 2... m), values such that:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = \left[\sum\nolimits_{i=1}^{n} l_i + \sum\nolimits_{i=1}^{n} m_i + \sum\nolimits_{i=1}^{n} u_i\right] \quad (3)$$

And then, compute the inverse of the vector above such that:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i} + \frac{1}{\sum_{i=1}^{n} m_i} + \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (4)$$

ii. Then fuzzy values which are obtained in the step 1 will be compared by following this procedure

The degree of the possibility that M2 = (l2, m2, u2) ≥ M1 = (l1, m1, u1) is defined as:

$$\mathrm{V}\,(\mathrm{M2} \geq \mathrm{M1}) = sup_{x\geq y}\ [min(\mu M_1\,(x), \mu M_2\,(y))] \quad (5)$$

And can be equivalently expressed as follows:

$$V(M2 \geq M1) = \begin{cases} 1, & if\ m_2 \geq m_1 \\ 0 & if\quad l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & otherwise \end{cases} \quad (6)$$

iii. Then priority (importance) weights will be calculated by using Equation (7)

V ($M_1, M_2, \ldots, M_k$) = min V ($M \geq M_i$), which can be defined by:

$d(A_i) = \min V\,(S_i \geq S_k)$, k = 1, 2,…, n; k ≠ I

(7)

iv. Finally, via normalization of the priority weights of attributes the vectors of normalized weight will be determined.

$$NW_i = \frac{W_i}{\sum W_i} \quad (8)$$

In addition, in Table 1 shows linguistic scales for importance comparison with triangle fuzzy number (TFN) for assisting comparisons has been proposed.

Table 1. Linguistic scales for importance comparison

Linguistic Scale	TFN
Absolutely important	(5/2, 3, 7/2)
Very important	(2, 5/2, 3)
important	(3/2, 2, 5/2)
Moderately important	(1, 3/2, 2)

Equally important	(1/2, 1, 3/2)
Just equal	(1, 1, 1)

2.2. Fuzzy TOPSIS

In [25], for the first time used fuzzy environment in the traditional TOPSIS approaches. Algorithm of fuzzy TOPSIS method which is describes by [25] are as follows:

i. Decision making team have been gathered together. Then, each decision maker rating weight should present in fuzzy environment as triangular fuzzy numbers.

ii. Criteria must be evaluated in second step.

iii. After calculation of each criterion, proper linguistic scales should be selected for weighting alternatives and criteria.

iv. In next step, the criteria aggregate weight must be evaluated. Aggregated fuzzy ratings present as follow:

$\tilde{R}_k = (a, b, c) \quad k = (1,2, \dots, k)$

where $a = \min_k \{a_k\}$, $b = \frac{1}{k}\sum_{k=1}^{k} b_k$, $c = \max_k \{c_k\}$ (9)

If $\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3})$ is each criterion fuzzy weights of, then it will evaluate as follow:

$$w_{j1} = \min_k \{w_{ij}\},\ w_{j2} = \frac{1}{k}\sum_{k=1}^{k} w_{jk2},\ w_{j3} = \max_k \{w_{jk3}\} \quad (10)$$

v. Next, normalized fuzzy decision matrix will be formed.

vi. In next step, by considering each criterion weights differences, the weighted normalized decision matrix should be multiplying the importance of evaluation criteria and the values in the normalized fuzzy decision matrix.

vii. Then, fuzzy positive ideal solution (FPIS, A^*) and fuzzy negative ideal solution (FNIS, A^-) are determined by:

$A^* = (\tilde{V}_1^*, \tilde{V}_2^*, \dots, \tilde{V}_n^*)$

$A^- = (\tilde{V}_1^-, \tilde{V}_2^-, \dots, \tilde{V}_n^-)$

where

$$\tilde{V}_j^* = \max_i \{v_{ij3}\}$$

$$\tilde{V}_j^- = \min_j \{v_{ij1}\} \quad (11)$$

$i = 1, 2, \dots, m;\ j = 1, 2, \dots, n$

viii. Next, for calculating the distance of each alternative from FPIS and FNIS, it can be proceeding as follow:

$$d_i^- = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}\,\tilde{v}_j^-\right),\; d_i^* = \sum_{j=1}^{n} d_v\left(\tilde{v}_{ij}\,\tilde{v}_j^*\right), i = 1, 2, \ldots, m \quad (12)$$

dv (. , .) is the measurement distance between two fuzzy numbers.

ix. The closeness coefficient CC_i which represents the fuzzy positive ideal solution A^* and negative ideal solution A^- simultaneously is computed as follow:

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad (13)$$

$i = 1, 2, \ldots, m$

Finally, when all alternatives' CCi is evaluated, the largest value for CC_i represent the best performance among alternatives. Hence, a large value of CC_i means alternative i performance is good.

3. RESULTS AND DISCUSSION

One of the biggest company in Malaysia, which produce a metal basket is chose as a case study for this research integrated model. This company decided to improve their products' environmental standards for improving competitive capability in global marketing, so green issues is one of the most important factors in their supplier selection problems. Fig. 3 presents important purchasing criteria for this firm's manager.

Majority raw material that purchased by this company is a steel sheet. Four existing suppliers can supply this firm's demand and this study aims to select most appropriate supplier. Purchasing management group is conducted pairwise comparisons based on different suppliers and criteria to calculate each criterion and sub-criteria weight. Tables 2 to 8 are presented criteria pairwise comparison matrixes:

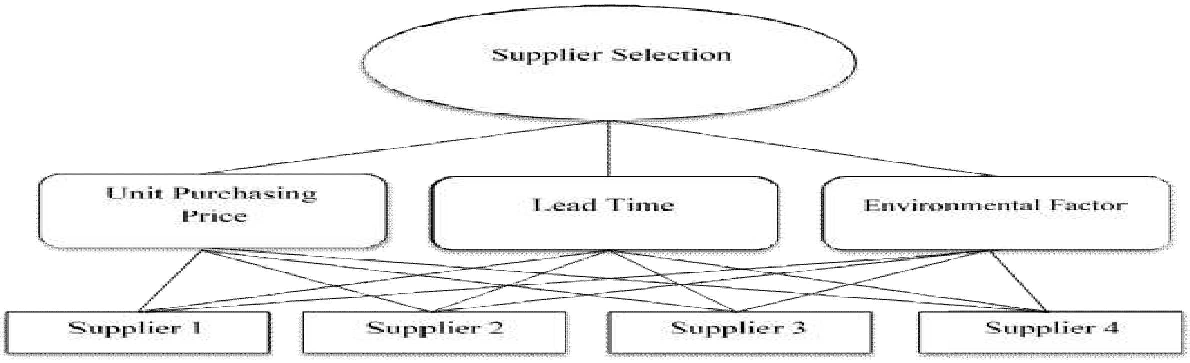

Fig.3. Hierarchical structure of the decision problem

Table 2. Importance of one main criterion over another

Criteria	Unit Purchasing Price	Lead Time	Environmental Factor
Unit purchasing price	(1,1,1)	(1,1.5,2)	(0.5,1,1.5)
Lead time	(0.5,0.67,1)	(1,1,1)	(0.67,1,2)
Environmental factor	(0.67,1,2)	(0.5,1,1.5)	(1,1,1)

Table 3. Importance of one sub-criterion over another

Environmental Factor	Environmental Management System	Pollution	Waste
EMS	(1,1,1)	(0.5,1,1.5)	(1.5,2,2.5)
Pollution	(0.67,1,2)	(1,1,1)	(1,1.5,2)
Waste	(0.4,0.5,0.67)	(0.5,0.67,1)	(1,1,1)

Table 4. Importance of one supplier over another in terms unit purchasing price

Unit Purchasing Price	S_1	S_2	S_3	S_4
S_1	(1,1,1)	(1,1.5,2)	(0.67,1,2)	(0.67,2,2.5)
S_2	(0.5,0.67,1)	(1,1,1)	(0.4,0.5,0.67)	(0.5,1,1.5)
S_3	(0.5,1,1.5)	(1.5,2,2.5)	(1,1,1)	(2,2.5,3)
S_4	(0.4,0.5,0.67)	(0.67,1,2)	(0.34,0.4,0.5)	(1,1,1)

Table 5. Importance of one supplier over another in terms of lead time

Lead Time	S1	S2	S3	S4
S1	(1,1,1)	(0.67,1,2)	(1,1.5,2)	(1,1,1)
S2	(0.5,1,1.5)	(1,1,1)	(1.5,2,2.5)	(0.5,1,1.5)
S3	(0.5,0.67,1)	(0.4,0.5,0.67)	(1,1,1)	(0.5,0.67,1)
S4	(1,1,1)	(0.67,1,2)	(1,1.5,2)	(1,1,1)

Table 6. Importance of one supplier over another in terms of EMS

EMS	S_1	S_2	S_3	S_4
S_1	(1,1,1)	(1.5,2,2.5)	(0.5,1,1.5)	(1,1.5,2)
S_2	(0.4,0.5,0.67)	(1,1,1)	(0.5,0.67,1)	(0.67,1,2)
S_3	(0.67,1,2)	(1,1.5,2)	(1,1,1)	(0.5,1,1.5)
S_4	(0.5,0.67,1)	(0.5,1,1.5)	(0.67,1,2)	(1,1,1)

Table 7. Importance of one supplier over another in terms of pollution

Pollution	S_1	S_2	S_3	S_4
S_1	(1,1,1)	(0.5,1,1.5	(0.5,0.67,1)	(0.67,1,2)
S_2	(0.67,1,2)	(1,1,1)	(0.4,0.5,0.67)	(0.5,0.67,1)
S_3	(1,1.5,2)	(1.5,2,2.5)	(1,1,1)	(0.5,1,1.5)
S_4	(0.5,1,1.5)	(1,1.5,2)	(0.67,1,2)	(1,1,1)

Table 8. Importance of one supplier over another in terms of waste

Waste	S_1	S_2	S_3	S_4
S_1	(1,1,1)	(1,1.5,2)	(0.5,1,1.5)	(0.67,1,2)
S_1	(1.5,0.67,1)	(1,1,1)	(0.67,1,2)	(0.5,0.67,1)
S_1	(0.67,1,2)	(0.5,1,1.5)	(1,1,1)	(0.67,1,2)
S_1	(0.5,1,1.5)	(1,1.5,2)	(0.5,1,1.5)	(1,1,1)

The weight of each criteria and sub-criteria based on 1-8 formula is calculated as follows:

$W'_{criteria} = (1, 0.811, 0.894)$

$W'_{sub\text{-}criteria} = (1, 0.892, 0.378)$

Equation (8) helps to calculate the final weight of each criteria and sub-criteria:

Table 9. Criteria final weight

Criteria	Unit Purchasing Price	Lead Time	Environmental Factor
Final Weight	0.37	0.30	0.33

Table 10. Sub-criteria final weight

Sub-Criteria	EMS	Pollution	Waste
Final Weight	0.44	0.39	0.17

After weigh to each criterion by FAHP method, Fuzzy TOPSIS is used to rank existing supplier and select appropriate one. Decision matrix is conducted to evaluate each supplier performance. Table 11 presents weighted normalized decision matrix for criteria and sub-criteria.

Table 11. Weighted normalized decision matrix

	Cost			Lead Time			Waste			Pollution			EMS		
S1	0.123	0.247	0.370	0.150	0.225	0.300	0.028	0.042	0.056	0.032	0.064	0.097	0.087	0.116	0.145
S2	0.123	0.123	0.247	0.075	0.150	0.225	0.014	0.028	0.042	0.064	0.097	0.129	0.029	0.058	0.087
S3	0.247	0.370	0.493	0.075	0.075	0.150	0.028	0.042	0.056	0.032	0.064	0.097	0.029	0.029	0.058
S4	0.123	0.247	0.370	0.075	0.150	0.225	0.028	0.042	0.056	0.064	0.097	0.129	0.029	0.058	0.087

To establish Fuzzy TOPSIS ranking, 11 formula is calculated FPIS and FNIS, in next step 12 formula is evaluated the distance of each alternative from FPIS and FNIS. Finally, for ranking the suppliers, formula 13 is calculated the CC_i for alternatives. Table 12 shows each supplier performance and ranking based on integrated FAHP and FTOPSIS method.

Table 12. Obtained results with fuzzy TOPSIS

Supplier	d_i^*	d_i^-	CC_i	Ranking
S1	0.063	0.1	0.614	1
S2	0.108	0.048	0.308	4
S3	0.106	0.05	0.319	3
S4	0.087	0.067	0.433	2

By considering FAHP results in Table 9 cost is the most significant factor for the case study, followed by that environmental issues.

Fuzzy TOPSIS results in Table 12 present that supplier 1 has the best CC_i (0.614) among other existing suppliers, after supplier 1 the second best CC_i (0.433) is belong to supplier 4. The last choice for raw material purchasing is supplier 2 with $CC_i = 0.308$. Hence, if single source can satisfy this firm's purchasing demand the most appropriate supplier is supplier 1, but if it need multiple suppliers, supplier 4 is the second-best supplier.

4. CONCLUSION

Green supplier selection in the supply chain network was the problem addressed in this research. Supplier selection is a MCDM problem which has an effect in the whole supply chain performance. This study used FAHP and fuzzy TOPSIS to find weight of important criteria, also rank the most appropriate suppliers.

This research provided a case study to analyze the significant criteria such as cost, delivery time and environmental factors, simultaneously for supplier selection problem in fuzzy environment. The results of this integrated model indicate the effect of each criteria on the selecting suppliers. In conclusion, this model aim decision managers to select appropriate suppliers and improve their competitive ability in marketing by reduce their cost, delivery time, respect to environmental factors.

5. ACKNOWLEDGEMENTS

The authors would like to thank University of Malaya for the financial supports under UMRG (RP035C-15AET).

6. REFERENCES

[1] Fallahpour A, Olugu E U, Musa S N, Khezrimotlagh D, Wong K Y. An integrated model for green supplier selection under fuzzy environment: application of data envelopment analysis and genetic programming approach. Neural Computing and Applications, 2016, 27(3):707-725

[2] Fallahpour A, Amindoust A, Antuchevičienė J, Yazdani M. Nonlinear genetic-based model for supplier selection: A comparative study. Technological and Economic Development of Economy, 2017, 23(1):178-195

[3] Fallahpour A, Olugu E U, Musa S N. A hybrid model for supplier selection: integration of AHP and multi expression programming (MEP). Neural Computing and Applications, 2017, 28(3):499-504

[4] Hashemzah P. The green supplier selection and order allocation in the supply chain under stochastic conditions. Phd thesis, Johor: Universiti Teknologi Malaysia, 2014

[5] Boran F E, Genç S, Kurt M, Akay D. A multi-criteria intuitionistic fuzzy group decision making for supplier selection with TOPSIS method. Expert Systems with Applications, 2009, 36(8):11363-11368

[6] Sanayei A, Mousavi S F, Yazdankhah A. Group decision making process for supplier selection with VIKOR under fuzzy environment. Expert Systems with Applications, 2010, 37(1):24-30

[7] Chen C C, Shih H S, Shyur H J, Wu K S. A business strategy selection of green supply chain management via an analytic network process. Computers and Mathematics with Applications, 2012, 64(8):2544-2557

[8] Jadidi O M, Zolfaghari S, Cavalieri S. A new normalized goal programming model for multi-objective problems: A case of supplier selection and order allocation. International Journal of Production Economics, 2014, 148:158-165

[9] Kazemi N, Ehsani E, Glock C H. Multi-objective supplier selection and order allocation under quantity discounts with fuzzy goals and fuzzy constraints. International Journal of Applied Decision Sciences, 2014, 7(1):66-96

[10] Talluri S, Narasimhan R, Nair A. Vendor performance with supply risk: A chance-constrained DEA approach. International Journal of Production Economics, 2006, 100(2):212-222

[11] Florez-Lopez R. Strategic supplier selection in the added-value perspective: A CI approach. Information Sciences, 2007, 177(5):1169-1179

[12] Ha S H, Krishnan R. A hybrid approach to supplier selection for the maintenance of a competitive supply chain. Expert Systems With Applications, 2008, 34(2):1303-1311

[13] Galankashi M R, Helmi S A, Hashemzahi P. Supplier selection in automobile industry: A mixed balanced scorecard–fuzzy AHP approach. Alexandria Engineering Journal, 2016, 55(1):93-100

[14] Xia W, Wu Z. Supplier selection with multiple criteria in volume discount environments. Omega, 2007, 35(5):494-504

[15] Demirtas E A, Üstün Ö. An integrated multiobjective decision making process for supplier selection and order allocation. Omega, 2008, 36(1):76-90

[16] Asgari M S, Abbasi A, Alimohamadlou M. Comparison of ANFIS and FAHP-FGP methods for supplier selection. Kybernetes, 2016, 45(3):474-489

[17] Tavana M, Fallahpour A, Di Caprio D, Santos-Arteaga F J. A hybrid intelligent fuzzy predictive model with simulation for supplier evaluation and selection. Expert Systems with Applications, 2016, 61:129-144

[18] Fallahpour A, Olugu E U, Musa S N, Khezrimotlagh D, Singh S. Supplier selection under fuzzy environment: A hybrid model using KAM in DEA. In 12th International Conference of DEA, 2014, pp. 342-348

[19] Ji F, Cai X, Zhang J. Wind power prediction interval estimation method using wavelet-transform neuro-fuzzy network. Journal of Intelligent and Fuzzy Systems, 2015, 29(6):2439-2445

[20] Xu H, Xing L, Huang L. Evaluation of scientific publications with hesitant fuzzy uncertain linguistic and semantic information. Journal of Intelligent and Fuzzy Systems, 2015, 29(6):2737-2742

[21] Zhang D, Zhang D, Xie J, Chen Y. An indirect tire identification method based on a two-layered fuzzy scheme. Journal of Intelligent and Fuzzy Systems, 2015, 29(6):2795-2800

[22] Xia G, Pang C, Xue J. Fuzzy neural network-based robust adaptive control for dynamic positioning of underwater vehicles with input dead-zone. Journal of Intelligent and Fuzzy Systems, 2015, 29(6):2585-2595

[23] Batyrshin I, Pamučar D S, Crippa P, Liu F. The fuzzy system and its application in East Asia. Journal of Intelligent and Fuzzy Systems, 2015, 29(6):2317-2318

[24] Chang D Y. Applications of the extent analysis method on fuzzy AHP. European Journal of Operational Research, 1996, 95(3):649-655

[25] Chen C T. Extensions of the TOPSIS for group decision-making under fuzzy environment. Fuzzy Sets and Systems, 2000, 114(1):1-9

How to cite this article:
Hashemzahi P, Musa SN, Yusof F. A hybrid fuzzy multi-criteria decision making model for green supplier selection. J. Fundam. Appl. Sci., 2017, 9*(4S), 417-429.*