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RESEARCH ARTICLE

AN INTEGRATED FUZZY AHP AND ENTROPY METHOD TO SUPPLIER SELECTION IN SUPPLY CHAIN UNDER FUZZY ENVIRONMENT

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ABSTRACT

Supplier performance evaluation and selection are multi criteria decision making problems.In supply chain, appropriate selection of vendor has become strategic problem. The decision of supplier selection is unstructured and complicated task purchasing managers of any company. Supplier evaluation process consists both quantitative and quantitative criteria. In this model, cost, quality, delivery, and production facility & capacity are considered in the process of measuring and selection of appropriate supplier.In this study, Fuzzy Analytical Hierarchical Process (FAHP) based on entropy weight is used to choose optimal supplier.The procedure of supplier selection process using fuzzy AHP based on entropy weight are explained with numerical example.

INTRODUCTION

Supply chain management (SCM) is a process to integrate and manage total flow of material from suppliers to final customer. The purpose of supply chain is to enhance customer value and gain competitive edge in a market. The process of supply chain consists three stages; procurement, production, and distribution.Recently, SCM has gained attention in business. Organizationsalways do effort for effective decision to select best supplier. In most firms, cost of materials and component parts represent main cost of product. In some firms, cost of product can be up to 70% of total cost(Ghodsypour & O'Brien, 1998) . Under these circumstances, decision making process of purchasing department of organizations play an important role to reduce the cost of product. Nowadays, in competitive environment, the process of effective supplier selection plays key role for success of any firms (Liu & Hai, 2005).Supplier selection is critical activity for purchasing manager in supply chain management. Supplier selection is a multi-criteria decision making problem. Selection of right supplier is difficult task for purchasing department. In the process of supplier selection, it is very important to evaluate supplier based on quantitative as well as qualitative criteria. There are two components of supplier selection problem, formulation of criteria and assessment of experts. The purpose of supplier selection is to choose optimal supplier that provide quality products and service to buyers. In order to choose right supplier, it is important to tradeoff between tangible and intangible attributes that may conflict. Nowadays, firms are facing most important business decision in supply chain is the right selection of supplier while satisfying multi-criteria quality, price, technical capability and delivery. In supply chain, supplier evaluation and selection of optimal supplier have been main point of researchers since 1960s. Traditionally, supplier evaluation process based on single criteria price. While price was considered very important criteria in supplier selection process. In order to measureoverall performance of supplier, several factors are needed to be take into account during supplier selection process. (Dickson, 1966)identified 23 criteria for the purpose of supplier selection including price, quality, technical capability, performance history, financial position and warranties. Quality is leading criteria among others. A multi-objective approach to vendor selection proposed to provide solution for purchasing manager for selection of multiple suppliers based on multiple criteria (Weber & Current, 1993).In last decade, researchers have developed a number of MCDM techniques to resolve supplier selection problem, which includes mathematical, statistical, artificial intelligence and integrated model. Data envelopment analysis (DEA) proposed to measure supplier' performance(Talluri & Sarkis, 2002). The mathematical programming model used to maximize revenue and satisfy customer needs by determining optimal order quantity and appropriate selection of supplier (Dong Sik Jang et al, 2005). It stated that vendor selection is critical activity in outsourcing. In vendor selection problem, three multi-objective functions were defined; to minimize price, lead time and rejections.

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Finally three methods weighted objective method, goal programming method, and compromising programming used to compare multi-objective optimization models (Wadhwa & Ravindran, 2007). An agent-based supply chain framework applied to determine suitable supplier and evaluate material in order to fulfil customer need using various criteria. Fuzzy case based reasoning used for substitution of products (Alireza Jahani et al, 2015).AHP model proposed to select most optimal supplier. Four different criteria were selected with 16 sub-criteria to evaluate supplier. In the process of ranking criteria, service quality was the most important factor among others (Betül Özkan et al, 2011).Analytical hierarchical process (AHP) it is a multi-criteria decision making problem. AHP applied to web based casting supplier evaluation. Quality capability, manufacturing capability, product development capability, cost, and delivery were selected to evaluate supplier. Selection of global supplier is more complex than domestic supplier.Fuzzy AHP applied to select global supplier based on both quantitative and qualitative criteria. It is an efficient tool to handle human vagueness in the process of deciding the priority of different factors (Felix T. S. Chan et al, 2008). In supply chain, supplier selection is considered most complicated task for purchasing department. AHP model applied to steel manufacturing company to choose best combination of suppliers (Farzad Tahriri et al, 2008). Selection of appropriate supplier based on lowest price is not sufficient. Supplier selection is a multi-criteria problem. Selection of vendor consists different criteria both quantitative and qualitative criteria. Supplier selection model AHP was formulated and applied to ABC Company to select best supplier. It is less time taking and multi-criteria decision making model for appropriate supplier selection (Alsuwehri, 2011).

Vendor selection problem is important component of inventory management. In the process of vendor evaluation various criteria were considered as price, quality, service, and delivery. The analytical hierarchical process approach selected to choose right vendor (Nydick & Hill, 1992).Appropriate selection of supplier is important issue in supply chain. The supplier evaluation process depends expert assessment. The existing AHP method is unable to control vagueness, impression. In order to overcome this situation D-numbers were used. D-AHP method proposed to select optimal supplier (Xinyang Deng et al, 2014).The analytical hierarchical process (AHP) introduced by(Saaty, 1980). AHP method one of mostly used method during the last decade. Saaty's AHP is a technique to represent components of problem through hierarchically and defines principles and procedure to synthesize judgment to determine priorities of various criteria and alternative solution. The AHP has some drawbacks. The way of ranking AHP is not precise. It deals with unbalance ratio of determination like that 1/9, 1/8,…., 1/3, 1/2, 1, 2, 3, 4, ……., 8, 9. These are reciprocal elements of matrices.In reciprocal matrix, half range of non-diagonal element are from 2 to 9 and another half range from 1/9 to 1/2 which are smaller as compare with former (2 to 9). In reciprocals part, the range of element about 1/2 – 1/9 = 0.4 other part is 9-2 = 7. The discrete scale 1 to 9 is simple but it does not consider uncertainty of human judgment(Cheng, 1997).To overcome these problems, a fuzzy scale for measuring weight criteria in hierarchical structure proposed by (Juang & Lee, 1991).In this paper, Fuzzy AHP method based on entropy weight is proposed to evaluate and select the supplier. The objective of appropriate supplier selection is to provide quality material at reasonable price at right time. In order to determine priority of criteria and sub-criteria, triangular fuzzy numbers are used.

The Proposed Model

Eigenvector method is another name of AHP. AHP is multi-criteria decision making method developed by (Saaty, 1980). AHP includes both measures subjective and objective. It is systematic procedure to solve multi-criteria decision making problem using both quantitative and qualitative factors.Fuzzy AHP is an extension of AHP which provides more efficient way to solve decision making problem as compared to traditional AHP. Triangular fuzzy number are used to determine priority of one criteria over another criteria. AHP is a systematic process to represent decision problem through hierarchical way. The top level of hierarchy shows objective of decision problem, after that criteria and sub criteria take place, bottom level shows the alternatives. The traditional AHP is unable to deal with vagueness and imprecise data. In order to calculate relative importance weight of criteria, linguistic terms can be taken into account to overcome uncertainty whose membership function are characterized using triangular fuzzy numbers. The calculation of triangular fuzzy numbers using interval arithmetic and alpha cuts, and others step to select appropriate supplier are explainedbelow.

The Steps of fuzzy AHP and Entropy method Cheng's (1996)

(Cheng, 1996)Theapplication procedure of fuzzy AHP and Entropy model for optimal selection of supplier can be described as given below;

- Develop hierarchical structure of supplier selection problem
- Construct membership function of criteria
- Calculate evaluation score of criteria
- Compute total weights using Fuzzy AHP and entropy method.

Calculation of fuzzy number using interval arithmetic and α-cuts

A triangular fuzzy number can be defined as (a_1, a_2, a_3). Where a_1 indicates lower value, a_2 shows middle value, and a_3 upper value. The membership functions of triangular fuzzy numbers can be defined as;

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

Alternatively, in order define interval of confidence at level α, we need to characterize the triangular fuzzy number as mention below;

$$\forall \alpha \in [0,1]$$

$$\tilde{A}_\alpha = [a_1^\alpha, a_3^\alpha]$$

$$= [(a_2 - a_1)\alpha + a_1, -(a_3 - a_2)\alpha + a_3] \quad (2)$$

Some operations of fuzzy number using interval of confidence can be described as follows:

$$\begin{aligned} &\forall a_L, a_R, b_R \in R^+, \tilde{A}_\alpha = [a_L^\alpha, a_R^\alpha], \\ &\tilde{B}_\alpha = [b_L^\alpha, b_R^\alpha], \alpha \in [0,1], \\ &\tilde{A} + \tilde{B} = [a_L^\alpha + b_L^\alpha, a_R^\alpha + b_R^\alpha], \\ &\tilde{A} - \tilde{B} = [a_L^\alpha - b_L^\alpha, a_R^\alpha - b_R^\alpha], \\ &\tilde{A} \times \tilde{B} = [a_L^\alpha b_L^\alpha, a_R^\alpha b_R^\alpha], \\ &\tilde{A} / \tilde{B} = [a_L^\alpha / b_R^\alpha, a_R^\alpha / b_L^\alpha] \end{aligned} \quad (3)$$

Where $\tilde{A}$ and $\tilde{B}$ are considered crisp values, $+, -, \times,$ and / denote addition, subtraction, multiplication and division of two intervals of confidence, respectively.

To compute total fuzzy judgment matrix $\tilde{A}$, first step is to multiply the fuzzy subjective weight vector $\tilde{W}$ with the corresponding column of fuzzy judgment matrix $\tilde{X}$ with each criteria. Thus

$$\tilde{A} = \begin{bmatrix} \tilde{w}_1 \times \tilde{x}_{11} & \tilde{w}_2 \times \tilde{x}_{12} & \cdots & \tilde{w}_n \times \tilde{x}_{1n} \\ \tilde{w}_1 \times \tilde{x}_{21} & \tilde{w}_2 \times \tilde{x}_{22} & \cdots & \tilde{w}_n \times \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{w}_1 \times \tilde{x}_{n1} & \tilde{w}_2 \times \tilde{x}_{n2} & \cdots & \tilde{w}_n \times \tilde{x}_{nn} \end{bmatrix} \quad (4)$$

Compute fuzzy number multiplication and addition using arithmetic and α-cuts

$$\tilde{A}_\alpha = \begin{bmatrix} [a_{11l}^\alpha, a_{11u}^\alpha] & \cdots & [a_{1nl}^\alpha, a_{1nu}^\alpha] \\ \vdots & \ddots & \vdots \\ [a_{n1l}^\alpha, a_{n1u}^\alpha] & \cdots & [a_{nnl}^\alpha, a_{nnu}^\alpha] \end{bmatrix} \quad (5)$$

Where $a_{ijl}^\alpha = w_{il}^\alpha x_{ijl}^\alpha, a_{iju}^\alpha = w_{iu}^\alpha x_{iju}^\alpha$, for $0 \prec \alpha \le 1$ and all i,j.

Next step is to calculate degree of satisfaction of judgment $\hat{A}$ with fixed α and index of optimism λ. The index of optimism λ shows degree of optimism of decision maker. A large value of λ shows a higher degree of optimism. The index of optimism is a linear convex combination, it can be explained as:

$$\hat{a}_{ij}^{\alpha} = (1-\lambda)a_{ijl}^{\alpha} + \lambda a_{iju}^{\alpha}, \forall \lambda \in [0,1] \quad (6)$$

Thus we have

$$\hat{A} = \begin{bmatrix} \hat{a}_{11}^{\alpha} \; \hat{a}_{12}^{\alpha} \cdots \hat{a}_{1n}^{\alpha} \\ \hat{a}_{21}^{\alpha} \; \hat{a}_{22}^{\alpha} \cdots \hat{a}_{2n}^{\alpha} \\ \vdots \quad \vdots \quad \ddots \quad \vdots \\ \hat{a}_{n1}^{\alpha} \; \hat{a}_{n2}^{\alpha} \cdots \hat{a}_{nn}^{\alpha} \end{bmatrix} \quad (7)$$

Where $\hat{A}$ is precise judgment matrix.

Entropy weight

Entropy introduced by Shannon(Klir & Yan, 1995)to measure uncertainty of information. Initially entropy weight derived from thermodynamics. The entropy weight function can be expressed as(Klir & Yan, 1995),

$$H\left(p_1, p_2, \ldots\ldots, \mathrm{p}_n\right) = -\sum_{i=1}^{n} p_i \log_2 p_i \quad (8)$$

Where p_i indicates relative frequency.

The entropy $H(p_1, p_2, \ldots, p_n)$ has unique form if it meets following three reasonable and compatible conditions, when

$$H\left(p_1, p_2, \ldots\ldots, \mathrm{p}_n\right) \le H\left(1/n, 1/n, \ldots\ldots, 1/n\right),$$
$$H\left(p_1, p_2, \ldots\ldots, \mathrm{p}_n\right) = H\left(p_1, p_2, \ldots\ldots, \mathrm{p}_n, 0\right),$$
$$H(AB) = H(A) + \mathrm{H(B/\,A)},$$

then

$$H\left(p_1, p_2, \ldots\ldots, \mathrm{p}_n\right) = -\sum_{i=1}^{n} p_i \log_2 p_i$$

Now, we propose the entropy weight computational method. Let A be a judgment matrix,

$$A = \begin{bmatrix} a_{11} \; a_{12} \cdots a_{1n} \\ a_{21} \; a_{22} \cdots a_{2n} \\ \vdots \quad \vdots \quad \ddots \quad \vdots \\ a_{n1} \; a_{n2} \cdots a_{nn} \end{bmatrix}$$

Let $M_k, k = 1, 2, \ldots, \mathrm{n},$ be sum of K_{th} row and f_{kj} be the relative frequency $f_{kj} = a_{kj} / \mathrm{m}_k$.

$$\begin{bmatrix} \frac{a_{11}}{s_1} & \frac{a_{12}}{s_1} & \cdots & \frac{a_{1n}}{s_1} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{a_{n1}}{s_n} & \frac{a_{n2}}{s_n} & \cdots & \frac{a_{nn}}{s_n} \end{bmatrix} = \begin{bmatrix} f_{11} \; f_{12} \cdots f_{1n} \\ \vdots \quad \vdots \quad \ddots \quad \vdots \\ f_{n1} \; f_{n2} \cdots f_{nn} \end{bmatrix} \quad (9)$$

Where $S_k = \sum_{j=1}^{n} a_{kj}$.

With the use of equation (9), we can calculate entropy,

$$H_1 = -\sum_{j=1}^{n} (f_{1j}) \log_2 (f_{1j})$$

$$H_2 = -\sum_{j=1}^{n} (f_{2j}) \log_2 (f_{2j})$$

$$\vdots$$

$$H_n = -\sum_{j=1}^{n} (f_{nj}) \log_2 (f_{nj}) \qquad (10)$$

Where H_i is i_{th} entropy value.

The entropy weight can be calculated by using Eq. (11)

$$H_i = \frac{H_i}{\sum_{j=1}^{n} H_j}, i = 1, 2, \ldots.., n \qquad (11)$$

The supplier with high priority weight will be selected as appropriate supplier for company.

Numerical Example

A company needs to select appropriate supplier to fulfill its requirement. Three suppliers are selected to choose best supplier among them. The evaluation process of selected supplier consists four attributes: cost, quality, delivery, and production facility & capacity. In the process of evaluation, linguistic judgment and triangular fuzzy number are used by decision makers to develop fuzzy judgment matrix. The hierarchical structure of decision problem is given below:

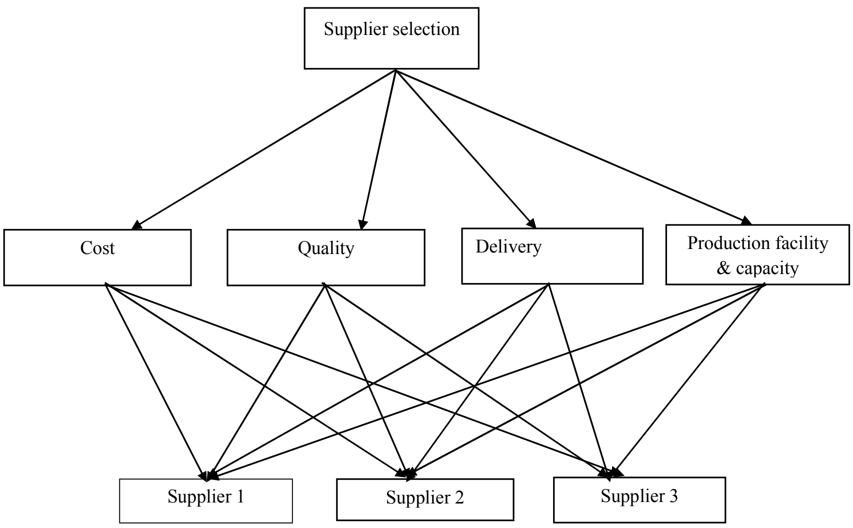

Figure.1 supplier selection problem hierarchical structure

Table 1. Triangular fuzzy numbers

Linguistic terms	Triangular fuzzy number
Equally important	(1,1,3)
Slightly important	(1,3,5)
Fairly important	(3,5,7)
Extremely important	(5,7,9)
Absolutely important	(7,9,9)

Table 2. Fuzzy judgment matrix

	Cost	Quality	Delivery	Production facility & capacity
Sup_1	(1,3,5)	(3,5,7)	(1,3,5)	(3,5,7)
Sup_2	(3,5,7)	(1,3,5)	(1,1,3)	(1,3,5)
Sup_3	(1,1,3)	(5,7,9)	(1,3,5)	(1,1,3)

Table 3.Fuzzy subjective weight vector

	Cost	Quality	Delivery	Production facility & capacity
W	(3,5,7)	(5,7,9)	(1,3,5)	(3,5,7)

To compute total fuzzy judgment matrix $\tilde{A}$, we can multiply fuzzy weight vector $\tilde{W}$ by corresponding column.

$\tilde{A}$ =

Cost	Quality	Delivery	P.F &C	
Sup_1	(3,5,7)×(1,3,5)	(5,7,9)×(3,5,7)	(1,3,5)×(1,3,5)	(3,5,7)×(3,5,7)
Sup_2	(3,5,7)×(3,5,7)	(5,7,9)×(1,3,5)	(1,3,5)×(1,1,3)	(3,5,7)×(1,3,5)
Sup_3	(3,5,7)×(1,1,3)	(5,7,9)×(5,7,9)	(1,3,5)×(1,3,5)	(3,5,7)×(1,1,3)

$$\forall_{\alpha} = [0,1],\ \tilde{A}_{\alpha} = \left[a_L^{\alpha}, a_R^{\alpha}\right] = \left[(a_2 - a_1)\alpha + a_1, -(a_3 - a_2)\alpha + a_3\right]$$

Fix α = 0.8 and λ = 0.5 for moderate decision.

$$\text{Cost} = \left[(a_2 - a_1)\alpha + a_1, -(a_3 - a_2)\alpha + a_3\right] \times \left[(a_2 - a_1)\alpha + a_1, -(a_3 - a_2)\alpha + a_3\right]$$

= [(5-3).8+3, - (7-5).8+7] × [(3-1).8+1, - (5-3).8+5]

= [4.6, 5.4] × [2.6, 3.4]

= [11.96, 18.36]

Same procedure applied to other criteria.

$\tilde{A}_{\alpha=0.8}$ =

Cost	Quality	Delivery	P.F &C	
Sup_1	[11.96, 18.36]	[30.36, 39.96]	[6.76, 11.56]	[21.16, 29.16]
Sup_2	[21.16, 29.16]	[17.16, 25.16]	[2.6, 4.76]	[11.96, 18.36]
Sup_3	[4.6, 7.56]	[43.56, 54.76]	[6.76, 11.56]	[4.6, 7.56]

To compute $\hat{A}^{\alpha}$, use λ = 0.5 using Eq. (6) as

$\hat{A}^{\alpha}$ = (1- 0.5) ×11.96+0.5×18.36 = 15.16

$\hat{A}^{\alpha}$ =

	Cost	Quality	Delivery	P.F &C
Sup_1	15.16	35.16	9.16	25.16
Sup_2	25.16	21.16	3.68	15.16
Sup_3	6.08	49.16	9.16	6.08

In order to compute relative frequency by using Eq. (9)

	Cost	Quality	Delivery	P.F &C
Sup_1	0.1791	0.4154	0.1082	0.2973
Sup_2	0.3861	0.3247	0.0565	0.2327
Sup_3	0.0862	0.6975	0.1299	0.0863

By using Eq. (10) we can calculate entropy value.

	Cost	Quality	Delivery	P.F &C
Sup_1	0.4444	0.5265	0.3471	0.5203
Sup_2	0.5301	0.5269	0.2342	0.4895
Sup_3	0.3048	0.3625	0.3825	0.3050

We calculate entropy values using relative frequencies and entropy formula Eq. (10). The next step is to determine normalized entropy values by using Eq. (11).

Entropy value	Entropy weight	
Sup_1	$H_1 = 1.8383$	0.3696
Sup_2	$H_2 = 1.7807$	0.3580
Sup_3	$H_3 = 1.3548$	0.2724

Supplier _1 is best choice for company due to high entropy weight.

Conclusion

Supplier selection is strategic issue in supply chain management and it becomes more critical issue for survival of companies in competitive environment. Appropriate selection of supplier enables companies to reduce cost, produce quality produce, and capture market share. In order to maintain consistent quality and increase competitiveness, implementation of supply chain system is important tool in companies. Under these circumstances, to build up long term relationship between manufacture and supplier is critical factor in supply chain.Selection of right supplier becomes an important issue in supply chain.In this paper, fuzzy AHP based on entropy weight is applied to select the best supplier. To determine importance weight of different criteria, linguistic terms and triangular fuzzy numbers are used. Fuzzy AHP can deal both qualitative and quantitative factor to select appropriate supplier.In fact, the proposed model is flexible and useful for supplier selection.In future, fuzzy synthetic evaluation model andlinguistic entropy method can be developed to select supplier.

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