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Supplier selection in supply chain management by using fuzzy multiple-attribute decision-making method

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Abstract. Supplier selection plays a key role in supply chain management that has received increasing emphasis at every place and has become an important strategic issue for its benefit. Researchers regarded the supplier selection process as a central issue in management decision. In fact, it can be viewed as a fuzzy multiple-attribute decision-making (FMADM) problem. However, in the past, few articles utilized FMADM methods to deal with the problem of supplier selection. In this paper, we identify empirically the quantitative and qualitative attributes and their corresponding importance weightings for selecting suppliers. Furthermore, a FMADM approach is employed to choose an optimum supplier from all possible supplier candidates.

Keywords: Supplier selection, fuzzy multiple-attribute decision-making

1. Introduction

Supply chain management (SCM) has received much attention at every place and it has become a central strategic issue for its benefit [9, 14]. Competitive advantages associated with SCM can be accomplished by means of strategic cooperation between buyers and suppliers [2, 5]. Therefore, supplier selection has been an extremely important issue in SCM.

Supplier selection by its nature involves evaluation and examination of suppliers according to multiple attributes (factors) and choice of the best preferred supplier to be part of supply chain. Numerous published articles has addressed and identified different attributes in various supplier selection problems [1, 8, 12, 18, 26]. Supplier selection needs to trade-off multiple attributes and process qualitative and quantitative data. Some studies had been reported to treat the problem of supplier selection such as discrete choice analysis [33], analytic hierarchical process (AHP) [3, 21], decision support system [16], artificial intelligent [10], mathematical programming (MP) [24, 29], and data envelopment analysis (DEA) [25, 30]. A real selection of supplier involves both assessing the characteristics of the suppliers in terms of different attributes and choosing the best supplier that is most preferred by decision makers. Supplier selection process is actually a multiple-attribute decision-making (MADM) problem. In real world, however, the available data used in decision-making problems are often imprecise and vague. Therefore, it can be viewed as a fuzzy multiple-attribute decision-making (FMADM) problem. In the past, several FMADM approaches had been proposed to treat various problems [6, 7, 11, 19, 20, 23, 31, 32,

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35]. However, few studies used FMADM approaches to solve supplier selection problem. Therefore, in this paper, we aim at employing a FMADM approach to solve the supplier selection problem. On the other hand, nowadays channel industry has been considered to be more important than manufacturing industry since the supply is frequently over the demand of market. Furthermore, because of the prosperous development of convenience marts in Taiwan, it motivates us to investigate convenience mart how to choose suppliers in supply chain although there have been no related researches addressing the issue of supplier selection in convenience mart yet. Since 1978, 7-Eleven has been a convenience mart in Taiwan. At present 7-Eleven has owned more than 3000 branches and has become the largest retailer in Taiwan. Meanwhile it has been the first leading one among convenience marts in Taiwan. In this study, we intend to identify empirically the attributes that consist of quantitative and qualitative attributes and are important to evaluate the supplier candidates of 7-Eleven convenience mart. In addition, we utilize the FMADM approach to deal with the supplier selection problem of 7-Eleven convenience mart.

The rest of this paper is organized as follows. In Section 2, a literature review of supplier selection and FMADM methods is given. In Section 3, a FMADM approach for solving supplier selection problem is presented. In Section 4, the attributes significant to assess the supplier candidates are identified empirically and the FMADM approach is applied to solving supplier selection problem. Finally, some conclusions are drawn.

2. Literature review

Supplier selection involves the need to evaluate a wide range of attributes that include qualitative and quantitative ones. These attributes usually conflict each other. Dickson [12] identified quality, cost and delivery performance as the three most important attributes. Since then, lots of conceptual and empirical articles for supplier selection have been reported [1, 4, 8, 18, 22, 26–28, 33, 34]. In spite of the richness of the earlier works in supplier selection, most articles only studied the decision makers' evaluation of the perceived importance of different attributes. They did not investigate how to choose the best supplier practically from all possible supplier candidates. Later, several approaches had been proposed for supplier selection by means of evaluating these candidates with respect to various attributes (requirements), such as discrete choice analysis, AHP, decision support system, artificial intelligent, MP, and DEA. Verma and Pullman [33] employed a Likert scale set of questions to determine the importance of supplier attributes and a discrete choice analysis experiment to investigate managers' actual choice of suppliers. They concluded that although quality was perceived to be the most important attribute, managers actually select suppliers mainly based on cost and delivery performance. Chan [3] offered an interactive selection model with AHP to decision makers in selecting suppliers. This model incorporated a method called chain of interaction that could be employed to evaluate the relative importance of attributes without subjective human judgment. Then, AHP was used to determine the overall score of individual supplier with respect to relative importance ratings of various attributes. Liu and Hai [21] developed an AHP-based approach to decide supplier. This approach is called voting analytic hierarchy process. They did not use pair-wise comparison of AHP to yield relative importance ratings of attributes. Instead, they employed a voting and ranking method to determine the order of attributes rather than the importance weightings. In this approach, AHP was only used to yield the individual score of supplier alternatives. Hou and Su [16] also developed an AHP-based decision support system to deal with supplier selection problem in a mass customization environment. They considered the factors from internal as well as external influences to satisfy the requirements of markets within the global changing environment. Choy et al. [10] proposed a case-based reasoning (CBR) based model to solve the supplier selection problem. Their model was implemented in a consumer products manufacturing company and could offer decision maker to choose a supplier best satisfying the need predefined by the company. Talluri and Narasimhan [29] developed a linear programming model for supplier selection problem in telecommunication company. The model was utilized to select potential suppliers according to the strengths of evaluated suppliers and reject poor suppliers from supplier alternatives. Ng [24] presented a weighted linear program for multiple attributes supplier selection problem. From supply base, this model tried to search for best supplier such that the supplier score is maximal. A chance-constrained DEA approach [30] is suggested to select suitable suppliers in the presence of multiple stochastic performance measures. In this approach, price was served as input while quality and delivery were viewed as output. Saen [25] thought that ordinal attributes should be taken into account in supplier selection problems and they were incapable of being quantified appropriately in certain situations. Consequently, he proposed a method to select the optimal supplier in the presence of both cardinal (quantitative) and ordinal (qualitative) data.

Supplier selection process is actually a multiple-attribute decision-making (MADM) problem. MADM refers to making decisions (e.g., selection, evaluation) over the available alternatives in the presence of multiple but usually conflicting attributes [17]. However, in many real applications (especially supplier selection problem), it is not surprising that uncertainty always exists [36]. For instance, very often the linguistic statement can be found in evaluating alternatives (suppliers) and/or in indicating the importance of attributes. As a result, supplier selection problem can be considered as a FMADM problem. Some published literatures had developed FMADM methods to solve a variety of problems such as selection of facility location, evaluation of service quality, evaluation of military weapon system and so on [6, 7, 19, 32]. Hwang and Yoon [17] proposed the technique for order preference by similarity to ideal solution (TOPSIS) which was one of the the most widely used MADM methods. It is based on the concept that the optimal alternative should have the minimal distance from the positive ideal solution and the maximal distance from the negative ideal solution in a geometrical sense. Negi [23] made the first attempt to apply TOPSIS in a fuzzy environment although he did not present new algorithm. Since then several researchers have proposed different fuzzy TOPSIS (FTOPSIS) approaches to deal with various FMADM problems [11, 19, 20, 31, 35]. However, they showed some shortcomings and consequently are unreliable. For instance, the conversion for quantitative attribute is unreliable [19, 20], the professional capability of decision maker is not took into account [11, 19, 20, 31, 35] or the ranking method is unreliable [11, 19, 20, 31]. Therefore, in this paper, an improved FTOPSIS approach is proposed to deal with supplier selection problem.

3. A FMADM approach for supplier selection problem

For supplier selection problem, we intend to utilize a FTOPSIS method to select the most satisfactory one from all possible supplier candidates. In this paper, both the weightings of importance with respect to all attributes and the ratings of all alternative under subjective attributes can be assessed by these decision-makers through linguistic values that are represented as positive triangular fuzzy numbers [13]. The linguistic value and its corresponding fuzzy number used to evaluate importance weightings of attributes as well as rate suppliers are shown in Table 1. The procedure of used FTOPSIS is described as follows.

Table 1
Linguistic value and fuzzy number

Linguistic value		Fuzzy number
Very unimportant (VU)	Very poor (VP)	(0, 0, 0.25)
Unimportant (U)	Poor (P)	(0, 0.25, 0.5)
Ordinary (O)	Medium (M)	(0.25, 0.5, 0.75)
Important (I)	Good (G)	(0.5, 0.75, 1)
Very important (VI)	Very good (VG)	(0.75, 1, 1)

Let $w_{sjq} = (d_{sjq}, e_{sjq}, f_{sjq})$, $0 \le d_{sjq} \le e_{sjq} \le f_{sjq} \le 1$, $s = 1, \ldots, k$, $j = 1, \ldots, u$, $q = 1, \ldots, p$, be the importance weighting of j-th sub-attribute C_{sj} of attribute C_s evaluated by decision-maker D_q. Let $w_{sq} = (d_{sq}, e_{sq}, f_{sq})$, $0 \le d_{sq} \le e_{sq} \le f_{sq} \le 1$, $s = 1, \ldots, k$, $q = 1, \ldots, p$, be the importance weighting of attribute C_s evaluated by decision-maker D_q. Let $x_{rsjq} = (g_{rsjq}, h_{rsjq}, t_{rsjq})$, $0 \le g_{rsjq} \le h_{rsjq} \le t_{rsjq} \le 1$, $r = 1, \ldots, n$, $s = 1, \ldots, i$, $j = 1, \ldots, u$, $q = 1, \ldots, p$, be the linguistic rating of alternative A_r in terms of j-th qualitative sub-attribute C_{sj} of attribute C_s evaluated by decision-maker D_q. Furthermore, if different professional capability of decision makers for evaluating a certain decision-making problem is considered, then the aggregated capability for m-th decision-maker can be calculated as

$$E_m = (1/(p-1)) \otimes \sum_{q=1, q \neq m}^{p} E_{qm}, \tag{1}$$

where E_{qm} represents the professional capability of m-th decision-maker evaluated by q-th decision-maker, $m = 1, \ldots, p$, $q = 1, \ldots, p$. Consequently, the aggregated results by p decision-makers can be summarized as follows:

$$x_{rsj} = (1/p) \otimes (x_{rsj1}E_1 \oplus x_{rsj2}E_2 \oplus \ldots \oplus x_{rsjp}E_p) \tag{2}$$

$$w_{sj} = (1/p) \otimes (w_{sj1}E_1 \oplus w_{sj2}E_2 \oplus \ldots \oplus w_{sjp}E_p) \tag{3}$$

$$w_s = (1/p) \otimes (w_{s1}E_1 \oplus w_{s2}E_2 \oplus \ldots \oplus w_{sp}E_p) \tag{4}$$

where x_{rsj} is the linguistic rating of alternative A_r in terms of j-th qualitative sub-attribute C_{sj} of attribute C_s, and w_s is the importance weighting of attribute C_s. On the other hand, let the benefit/cost associated with alternative A_r for sub-attribute C_j of quantitative attribute C_s be represented by $b_{rsj} = (b_{rsj1}, b_{rsj2}, b_{rsj3})$, $r = 1, \ldots,$

$n, s = i+1, \ldots, k, j = 1, \ldots, u$, where $(i+1)$ is associated with the quantitative attribute. Then, the suitable ratings of alternatives A_r with respect to sub-attribute C_j of C_s as $x_{rsj} = (g_{rsj},\ h_{rsj},\ t_{rsj})$ for $r = 1, \ldots, n$, $s = i+1, \ldots, k$, $j = 1, \ldots, u$, can be yielded through the following transformation:

$$x_{rsj} = \left(1/\alpha_{sj}\right)\left(b_{rsj1},\ b_{rsj2},\ b_{rsj3}\right) \tag{5}$$

where $\alpha_{sj} = \max_r b_{rsj3}$. The synthesized rating of alternative A_r with respect to attribute C_s that consists of u sub-attributes can be calculated as

$$x_{rs} = (1/u) \otimes \sum_{j=1}^{u} (x_{rsj} \otimes w_{sj}). \tag{6}$$

With x_{rs} and w_s, $r = 1, \ldots, n$, $s = 1, \ldots, k$, one can get the entry of weighted normalized fuzzy decision matrix can be calculated as [15]

$$\begin{aligned}\overline{x_{rs}} &= x_{rs} \otimes w_s = (g_{rs}, h_{rs}, t_{rs}) \otimes (d_s, e_s, f_s)\\ &= (\min(g_{rs}e_s, h_{rs}d_s), h_{rs}e_s, \max(e_s t_{rs}, f_s h_{rs})).\end{aligned} \tag{7}$$

It can be denoted by $\overline{x_{rs}} = (v_{rs}, y_{rs}, z_{rs})$, $0 \leq v_{rs} \leq y_{rs} \leq z_{rs} \leq 1$, for $r = 1, \ldots, n$, $s = 1, \ldots, k$. Then, the fuzzy positive ideal solution A^+ and fuzzy negative ideal solution A^- can be formed as follows:

$$A^+ = \left\{\left(\underline{x}_s^+ | s \in U\right), \left(\underline{x}_s^- | s \in V\right)\right\}, \tag{8}$$

$$A^- = \left\{\left(\underline{x}_s^- | s \in U\right), \left(\underline{x}_s^+ | s \in V\right)\right\} \tag{9}$$

where $\underline{x}_s^+ = (1, 1, 1)$, $\underline{x}_s^- = (0, 0, 0)$, U is the set of benefit attributes, and V is the set of cost attributes. One can find the difference between $\overline{x_{rs}}$ and $\underline{x}_s^+$ as

$$\delta_{rs}^+ = 3 - \left({}^1\!/_3\right)(v_{rs} + 4y_{rs} + 4z_{rs}). \tag{10}$$

Also, the difference between $\overline{y_{rs}}$ and $\underline{y}_s^-$ can be obtained as

$$\delta_{rs}^- = \left({}^1\!/_3\right)(4v_{rs} + 4y_{rs} + z_{rs}). \tag{11}$$

Next, from (8)–(11), the differences between A_r and A^+, A_r and A^- can be represented as

$$\begin{aligned}\beta_r^+ &= \left\{\left(\delta_{rs}^+ | s \in U\right), \left(\delta_{rs}^- | s \in V\right)\right\}\\ &= \left\{\theta_{r1}^+, \theta_{r2}^+, ..., \theta_{rk}^+\right\}.\end{aligned} \tag{12}$$

and

$$\begin{aligned}\beta_r^- &= \left\{\left(\delta_{rs}^- | s \in U\right), \left(\delta_{rs}^+ | s \in V\right)\right\}\\ &= \left\{\theta_{r1}^-, \theta_{r2}^-, ..., \theta_{rk}^-\right\},\end{aligned} \tag{13}$$

respectively. Then, from (10)–(13), the separation distances between alternative A_r and A^+, A_r and A^-can be determined to be

$$\omega_r^+ = \sum_{s=1}^{k} \theta_{rs}^+ \tag{14}$$

and

$$\omega_r^- = \sum_{s=1}^{k} \theta_{rs}^-, \tag{15}$$

respectively. The relative closeness of alternative A_r with respect to A^+ is defined as

$$S_r = \frac{\omega_r^-}{\omega_r^+ + \omega_r^-}, 0 \leq S_r \leq 1, r = 1, 2, ..., n. \tag{16}$$

One can see from (16) that A_r is closer to A^+ than to A^- as A_r has the larger S_r. Consequently, S_r can be employed to find the ranking order of all alternatives.

4. Empirical results

With the prosperous development of convenience marts in Taiwan, it gives a motive to study supplier selection problem for convenience mart although there never been related researches addressing this issue yet. Additionally, since very few reported literatures uses FTOPSIS methods to tackle supplier selection problem, our study attempts to employ it to deal with supplier selection problem of convenience marts.

Lots of attributes and sub-attributes concerning supplier selection had been reported in the open literatures. We synthesize them through literature review for supplier selection of convenience marts in Table 2 in which a 2-level hierarchy structure of attributes is constructed. Next, a pilot study is provided for supplier selection of convenience marts in Taiwan. We offer seven attributes and nineteen sub-attributes as shown in Table 2 to experts for identifying attributes which are significant to supplier selection of convenience marts.

After interviewing experts, all of these attributes and sub-attributes are identified to be significant except one sub-attribute is identified to be less significant to supplier selection of convenience marts in Taiwan. This sub-attribute is breadth of product line. Since we aim to apply the FTOPSIS approach to dealing with the supplier selection problem of convenience marts in Taiwan, the data collection is very important to our study. At first, four decision makers in

Table 2
Attributes for supplier selection

Attributes for supplier selection	Authors
Product	
Quality of product	Dickson [12], Anderson et al. [1], Choi and Hartley [8], Kannan and Tan [18], Shipley and Prinja [27], Narasimhan [22], Chapman [4]
Sales of product	Swift [28]
Breadth of product line	Swift [28]
Package of product	Swift [28]
Incremental improvement of product	Choi and Hartley [8]
Cost	
Total cost of product	Giannakis and Croom [14], Dickson [12], Sarkis and Talluri [26], Anderson et al. [1], Choi and Hartley [8], Kannan and Tan [18], Swift [28], Chapman [32]
Service	
	Giannakis and Croom [14], Choi and Hartley [8], Swift [28]
After-sales service support available	
Service capability	Giannakis and Croom [14], Sarkis and Talluri [26], Kannan and Tan [18]
Service response time	Giannakis and Croom [14], Sarkis and Talluri [26], Kannan and Tan [18], Swift [28]
Finance	
Supplier's financial condition	Choi and Hartley [8], Kannan and Tan [18], Swift [28], Narasimhan [22]
Supplier's profit capability	Kannan and Tan [18], Swift [28]
Relationship	
Reputation of suppliers	Sarkis and Talluri [26], Choi and Hartley [8], Swift [28]
Long-term cooperative relationship	Sarkis and Talluri [26], Choi and Hartley [8], Shipley and Prinja [27]
Strategic fit	Sarkis and Talluri [26], Kannan and Tan [18]
Flexibility	
Flexibility in changing the order	Sarkis and Talluri [26], Anderson et al. [1], Choi and Hartley [8], Verma and Pullman [33]
Conflict resolution	Sarkis and Talluri [26]
Delivery performance	Dickson [12], Sarkis and Talluri [26], Anderson et al. [1], Choi and Hartley [8], Kannan and Tan [18], Swift [28]
Short lead time	Choi and Hartley [8]
Technological capability	
Technical support available	Giannakis and Croom [14], Sarkis and Talluri [26], Choi and Hartley [8], Kannan and Tan [18], Swift [28]

7-Eleven are interviewed and each decision maker is asked to evaluate the professional capability of other decision-makers. Then, decision makers are asked to evaluate the weights of attributes and sub-attributes for rating supplier candidates. Eventually, they rate four main supplier candidates of 7-Eleven in terms of these attributes and sub-attributes. After collecting these data, this study proceeds to apply the FTOPSIS method for supplier selection in convenience marts. The ranking order of supplier candidates can be obtained through the following steps:

Step 1: After a preliminary screening, four candidates A_1, A_2, A_3 and A_4 are selected for further evaluation. A committee of four decision-makers, D_1, D_2, D_3, and D_4 is formed to choose the most suitable supplier. The professional capability of decision-makers is first evaluated by each other and the rating score is shown in Table 3.

Step 2: The decision-makers are asked to utilize linguistic variables to evaluate the importance weight of each attribute and sub-attribute. The evaluation results are shown in Tables 4 and 5, respectively. In addition, the decision-makers make use of linguistic variables to assess the rating of alternatives in terms of each sub-attribute. The linguistic ratings of four supplier alternatives are shown in Table 6.

Step 3: By (3)∼(16), the relative closeness coefficient of each alternative with respect to A^+ can also be computed. These results are shown in Table 7. Obviously, the ranking order for the four suppliers is A_2, A_4 ,A_1, A_3. Therefore, the optimal supplier is A_2.

Table 3
Professional capability of decision-maker

Decision-maker	D_1	D_2	D_3	D_4	Professional capability
D_1	-	1	0.75	1	0.92
D_2	0.50	-	0.75	1	0.75
D_3	0.75	1	-	1	0.92
D_4	0.50	0.75	0.75	-	0.6

Table 4
The importance weight of each attribute

Attributes	Decision-maker			
	D_1	D_2	D_3	D_4
Product (C_1)	I	VI	I	VI
Cost (C_2)	VI	VI	VI	VI
Service (C_3)	I	VI	VI	VI
Finance (C_4)	O	I	VI	VI
Relationship (C_5)	O	VI	VI	VI
Flexibility (C_6)	I	VI	VI	VI
Technological capability (C_7)	I	VI	VI	VI

Table 5
The importance weight of each sub-attribute

Sub-attribute	Decision-maker			
	D_1	D_2	D_3	D_4
C_{11}	VI	VI	VI	VI
C_{12}	I	VI	VI	VI
C_{13}	I	VI	I	VI
C_{14}	O	I	I	VI
C_{21}	VI	VI	VI	VI
C_{31}	I	VI	VI	VI
C_{32}	I	VI	I	VI
C_{33}	VI	VI	VI	VI
C_{41}	I	VI	VI	VI
C_{42}	O	I	VI	VI
C_{51}	I	VI	VI	VI
C_{52}	VI	VI	VI	VI
C_{53}	O	I	VI	VI
C_{61}	I	VI	VI	I
C_{62}	I	VI	VI	VI
C_{63}	VI	VI	VI	VI
C_{64}	I	VI	VI	VI
C_{71}	I	VI	VI	VI

5. Managerial implications

In this paper, we have integrated the hierarchical framework and FMADM approach to effectively deal with the supplier selection problem of 7-Eleven convenience mart. We investigate the evaluation of significant attributes for supplier selection, and we present a FTOPSIS method as a tool to choose the optimum supplier. To be specific, the linguistic statement can be used to indicate the importance of attributes and evaluate alternatives (suppliers) in the evaluation framework. First of

Table 6
The performance rating of each alternative vs. different sub-attribute

Sub-atribute	Alternative	Decision-maker			
		D_1	D_2	D_3	D_4
C_{11}	A_1	G	VG	G	VG
	A_2	M	G	G	G
	A_3	G	VG	VG	VG
	A_4	VG	VG	G	VG
C_{12}	A_1	M	M	VG	G
	A_2	G	VG	G	VG
	A_3	G	VG	G	G
	A_4	M	G	VG	G
C_{13}	A_1	M	G	VG	G
	A_2	G	VG	VG	G
	A_3	M	M	G	G
	A_4	M	G	G	VG
C_{14}	A_1	M	G	M	VG
	A_2	M	G	VG	G
	A_3	P	M	G	G
	A_4	G	VG	G	G
C_{21}	A_1	M	G	VG	G
	A_2	G	G	G	VG
	A_3	G	G	VG	VG
	A_4	M	G	G	G
C_{31}	A_1	P	M	G	G
	A_2	P	M	G	M
	A_3	P	M	G	G
	A_4	M	M	G	G
C_{32}	A_1	M	M	M	M
	A_2	P	M	G	M
	A_3	M	G	VG	G
	A_4	P	M	G	G
C_{33}	A_1	P	M	G	M
	A_2	P	G	G	G
	A_3	M	G	VG	G
	A_4	P	M	G	VG
C_{41}	A_1	G	G	G	VG
	A_2	M	M	VG	M
	A_3	P	G	G	M
	A_4	M	G	VG	G
C_{42}	A_1	G	M	M	VG
	A_2	M	M	G	G
	A_3	M	VG	M	G
	A_4	P	M	G	M
C_{51}	A_1	G	VG	G	G
	A_2	G	VG	VG	M
	A_3	P	M	M	G
	A_4	M	G	VG	G
C_{52}	A_1	M	G	G	VG
	A_2	M	G	G	G
	A_3	P	M	G	G
	A_4	P	M	G	G
C_{53}	A_1	M	G	G	G
	A_2	P	M	G	G
	A_3	P	M	M	M
	A_4	P	M	M	G

Table 6
(Continued)

Sub-atribute	Alternative	Decision-maker			
		D_1	D_2	D_3	D_4
C_{61}	A_1	G	VG	VG	VG
	A_2	P	G	G	M
	A_3	VP	P	M	M
	A_4	G	VG	VG	G
C_{62}	A_1	P	M	G	G
	A_2	M	VG	VG	G
	A_3	P	M	M	G
	A_4	M	G	VG	G
C_{63}	A_1	M	VG	G	G
	A_2	P	G	VG	M
	A_3	M	G	G	M
	A_4	M	G	VG	G
C_{64}	A_1	P	G	VG	G
	A_2	M	G	G	G
	A_3	P	G	VG	G
	A_4	M	G	G	VG
C_{71}	A_1	M	G	G	G
	A_2	G	VG	VG	VG
	A_3	P	M	G	M
	A_4	G	VG	VG	VG

Table 7
The relative closeness of each alternative

Alternative	ω^+	ω^-	S
A_1	13.2651	6.1578	0.31704
A_2	12.9240	6.5985	0.33799
A_3	13.8076	5.6473	0.29028
A_4	13.0034	6.5103	0.33363

all, we synthesized some attributes and sub-attributes through literature review for supplier selection of convenience marts. Next, in order to examine whether these attributes and sub-attributes are exactly important to the selection of optimum supplier, a pilot study is executed by experts of supplier selection. It is found that only one sub-attribute is identified to be less important to supplier selection of convenience marts in Taiwan. The sub-attribute is breadth of product line. After interviewing four decision makers in 7-Eleven to implement supplier selection, we find that five sub-attributes are most concerned by decision makers and viewed as "very important" ones. They are quality of product, total cost of product, service response time, long-term cooperative relationship and delivery performance. These findings are useful for both buyer and supplier. The buyer can select the optimum supplier according to these results. The supplier can use them from a marketing perspective and enhance these considered important attributes.

Furthermore, the rationale for the use of FMADM is due to the fact that it can select the best alternative under multiple but usually conflicting criteria from all possible candidates (suppliers) in a fuzzy environment. To be specific, it can integrate quantitative and qualitative data into decision model. As a consequence, it is quite suitable to be used to handle supplier selection problem in practices. Besides, it considers different professional capability of decision makers in supplier selection problem. Moreover, the proposed method has sound logic and simple computational process. It is easy to utilize and understand. This implies that the evaluation framework can be easily computerized and suitably served as a decision making tool by decision maker. These results can also be applied from both buyers' and suppliers' prospective. The buyer can decide the optimum supplier by means of the proposed decision model. On the other hand, the supplier can employ the proposed decision model to examine the competitive advantage in itself. In particular, this study contributes to management issue in researches and practices. In research fields, the proposed approach is applicable to numerous fields such as management science, economics, decision theory, education, marketing research, transportation, military research, and public administration. In practices, this study makes the first attempt at using FMADM approach to deal with the supplier selecting problem of convenience marts in Taiwan. The proposed FTOPSIS method can also be used to treat the supplier selection problem of other industries with different evaluation attributes. The results of this study can motivate more researchers to develop and/or use FMADM methods to solve the supplier selection problem in SCM.

6. Conclusions and suggestions

6.1. Concluding remarks

Lots of articles have addressed the importance and advantages of SCM. A successful supply chain must depend on nice selection of suppliers. Supplier selection involves processing qualitative and quantitative attributes that are used to evaluate suppliers and needing to trade-off multiple attributes that usually conflict one another. As a matter of fact, it can be considered as a FMADM problem. However, in the past very few studies utilized FMADM methods to deal with the problem of supplier selection. Moreover, with the prosperous development of convenience marts in Taiwan, it is worth investigating the supplier selection problem of convenience marts although none of related researches studied this issue yet. The purpose of this paper is to identify empirically the quantitative and qualitative attributes for supplier selection of convenience marts in Taiwan. Furthermore, a hierarchical decision framework with FTOPSIS method is employed to treat the supplier selection problem of convenience marts in Taiwan. Numerous attributes and sub-attributes regarding supplier selection can be found in the open literatures. By synthesizing some attributes and sub-attributes for supplier selection, we provide experts with these results for progressing pilot study. They identify seven significant attributes and eighteen significant sub-attributes. Then, after a preliminary screening of supplier candidates, four candidates are picked out by a committee of four decision-makers in 7-Eleven for further assessment to select the best supplier. Meanwhile, an improved FTOPSIS method is applied to deciding the optimum supplier. It can handle decision problem without those drawbacks appearing in earlier works. Finally, the ranking order for four alternative suppliers can be obtained by calculating relative closeness coefficient and the best preferred supplier is selected. The proposed approach can treat the supplier selection problem in the presence of the quantitative and qualitative attributes in a fuzzy environment. This study expands the application area of fuzzy sets theory. Also, this study contributes to supplier selection problem in industries and research fields. It is definitely capable of assisting both the decision makers and researchers in dealing with the supplier selection problem effectively.

6.2. Limitations and future researches

The proposed approach works well, but it still has some limitations. The larger the number of decision makers is, the more inconsistent the result of the FTOPSIS approach may be. Once the number of decision makers becomes more, it may cause a certain degree of inconsistency and hence degrade quality of decision. Furthermore, the poorer professional capability of decision maker will probably cause the decision model to fail in spite that the proposed model has considered the different professional capability of decision makers for evaluating and selecting supplier.

In the future, applications to supplier selection problems in various industries will also be made. Moreover, the success of supplier selection in supply chain may not completely rely upon these generally considered factors, it possibly needs to take various factors into account to enable the decision model to become more perfect.

References

[1] J.C. Anderson, G. Cleveland and R.G. Schroeder, Operations strategy: A literature review, *Journal of Operations Management* **8** (1989), 133–158.

[2] K.S. Bhutta and F. Huq, Supplier selection problem: A comparison of the total cost of ownership and analytic hierarchy process approaches, *Supply Chain Management* **7**(3) (2002), 126–135.

[3] F.T.S. Chan, Interactive selection model for supplier selection process: An analytical hierarchy process approach, *International journal Production Research* **41**(15) (2003), 3549–3579.

[4] S.N. Chapman, Just-in-time supplier inventory: An empirical implementation Model, *International Journal of Production Research* **27** (1993), 329–334.

[5] I.J. Chen and A. Paulraj, Understanding supply chain management: Critical research and a theoretical framework, *International Journal of Production Research* **42**(1) (2004), 131–163.

[6] S.J. Chen and C.L. Hwang, *Fuzzy Multiple Attribute Decision Making. Lecture Notes in Economics and Mathematical Systems*, Springer-Verlag, Berlin Heidelberg, 1992, pp. 292–351.

[7] C.H. Cheng and D.L. Mon, Evaluating weapon system by analytical hierarchy process based on fuzzy scales, *Fuzzy Sets and Systems* **63** (1994), 1–10.

[8] T.Y. Choi and J.L. Hartley, An exploration of supplier selection practices across the supply chain, *Journal of Operations Management* **14** (1996), 333–343.

[9] S. Chopra and P. Meindl, Supply Chain Management: Strategy, planning and Operations. Prentice Hall, New Jersey, 2007, pp. 1–4.

[10] K.L. Choy, W.B. Lee and V. Lo, A knowledge-based supplier intelligence retrieval system for outsource manufacturing, *Knowledge-Based Systems* **18**(1) (2005), 1–17.

[11] T.C. Chu, Facility location selection using fuzzy TOPSIS under group decisions, *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems* **10** (2002), 687–701.

[12] G.W. Dickson, An analysis of Vendor selection systems and decisions, *Journal of Purchasing* **2** (1966), 5–17.

[13] D. Dubois and H. Prade, Operations on fuzzy numbers, *International Journal of Systems Science* **9** (1978), 613–626.

[14] M. Giannakis and S.R. Croom, Toward the development of a supply chain management paradigm: A conceptual framework, *Journal of Supply Chain Management* **40** (2004), 27–37.

[15] D.H. Hong, Shape preserving multiplications of fuzzy numbers, *Fuzzy Sets and Systems* **123** (2001), 81–84.

[16] J. Hou and D. Su, EJB-MVC oriented supplier selection system for mass customization, *Journal of Manufacturing Technology Management* **18**(1) (2007), 54–71.

[17] C.L. Hwang and K. Yoon, *Multiple Attribute Decision Making: Methods and Applications*, Springer-Verlag, New York, 1981, pp. 3–10.

[18] V.R. Kannan and K.C. Tan, Supplier selection and assessment: Their impact on business performance, *Journal of Supply Chain Management* **38**(4) (2002), 11–21.

[19] G.S. Liang, Fuzzy MCDM based on ideal and anti-ideal concepts, *European Journal of Operational Research* **112** (1999), 682–691.

[20] T.S. Liou and M.J.J. Wang, Ranking fuzzy numbers with integral value, *Fuzzy Sets and Systems* **50** (1992), 247–255.

[21] F.H.F. Liu and H.L. Hai, The voting analytic hierarchy process method for selecting supplier, *International Journal of Production Economics* **97**(3) (2005), 308–317.

[22] R. Narasimhan, An analytical approach to supplier selection, *Journal of Purchasing Materials Management*, Winter (1983), 27–32.

[23] D.S. Negi, *Fuzzy analysis and optimization*, Ph. D. Thesis, Department of Industrial Engineering, Kansas State University, 1989, pp. 27–53.

[24] W.L. Ng, An efficient and simple model for multiple criteria supplier selection problem, *European Journal of Operational Research* **186**(3) (2008), 1059–1067.

[25] R.F. Saen, Supplier selection in the presence of both cardinal and ordinal data, *Eur J Operat Res* **183** (2007), 741–747.

[26] J. Sarkis and S. Talluri, A model for strategic supplier selection, *Journal of Supply Chain Management* **38**(1) (2002), 18–28.

[27] D. Shipley and S. Prinja, The services and suppler choice influences of industrial distributors, *Service Industries Journal* **8** (1988), 176–187.

[28] C.O. Swift, Preferences for single sourcing and supplier selection criteria, *Journal of Business Research* **32**(2) (1995), 105–111.

[29] S. Talluri and R. Narasimhan, A note on "a methodology for supply base optimization", *IEEE Transactions on Engineering Management* **52**(1) (2005), 130–139.

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

[31] C. T. Tsao and T. C. Chu, An improved fuzzy MCDM model based on ideal and anti-ideal concepts, *Journal of the Operation Research Society of Japan* **45**(2) (2002), 185–197.

[32] S.H. Tsaur, T.Y. Chang and C.H. Yen, The evaluation of airline service quality by fuzzy MCDM, *Tourism Management* **23** (2002), 107–115.

[33] R. Verma and M.E. Pullman, An analysis of the supplier selection process, *OMEGA International Journal of Management Science* **26**(6) (1998), 739–750.

[34] C.A.J.R. Weber and W.C. Benton, Vendor selection criteria and methods, *European Journal of Operational Research* **50** (1991), 2–18.

[35] W.Y. Wu, C. Lin, J.Y. Kung and C.T. Lin, A new fuzzy TOPSIS for fuzzy MADM problems under group decisions, *Journal of Intelligent & Fuzzy Systems* **18** (2007), 109–115.

[36] L.A. Zadeh, The concept of' a linguistic variable and its application to approximate reasoning, *Information Science* **8** (1975), 199–249 (I), 301–357(II).