AN INTERVAL-VALUED FUZZY NUMBER APPROACH FOR SUPPLIER SELECTION

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ABSTRACT

Supplier assessment in supply chain management and electronic marketplaces plays an important role in the business transaction. Many methods have been proposed to deal with the supplier selection problems. Some of them are based on fuzzy set theory. However, traditional fuzzy numbers cannot precisely express the vagueness in the decision process. In this paper, we are going to propose a new fuzzy multiple criteria decision making model based on interval-valued fuzzy numbers to tackle the supplier selection problem in the circumstances where uncertainty is introduced. Usually, fuzzy numbers are employed to express uncertainty. For a fuzzy number, the degree of the membership is a crisp number whereas the degree of the membership for an interval-valued fuzzy number is an interval. To grasp the vagueness more precisely, we employ interval-valued fuzzy numbers to represent the ratings and weights of the evaluation instead of traditional fuzzy numbers. One of the merits of our method compared to the traditional fuzzy methods is that our method can express the uncertainty more precisely in the evaluation process. Beside, we propose a new ranking method for interval-valued fuzzy numbers.

I. INTRODUCTION

E-commerce plays an important role in today's business transactions. There are four types of E-Commerce, namely, B2B, B2C, C2B and C2C. As indicated by the Economic Review of the Federal Reserve Bank of Kansas City, B2B e-commerce sales grew at an annual rate of 5.5 percent in the United States (Willis, 2004). Electronic marketplaces have played the role of aggregating the supply and demand from supplier and customers. Selecting appropriate suppliers is a complicated issue because of the selection criteria composed of quantitative and qualitative criteria (Choy et al., 2002). Therefore, electronic marketplaces make an effort to provide effective decision support services for supplier assessment and selection to their participants in order to enhance their satisfaction and loyalty (Bartels, 2005).

Contemporary supply chain management is to maintain long term partnership with suppliers, and use fewer but reliable suppliers. Therefore, choosing the right suppliers involves much more factors than simple screening a list of suppliers. Extensive multi-criteria decision making approaches have been proposed for supplier selection, such as analytic hierarchy process (AHP) (Chan and Kumar, 2007; Hou and Su, 2007), analytic network process (ANP) (Bayazit, 2006; Gencer and Gürpinar, 2007) case-based reasoning (CBR) (Choy et al., 2002), data envelopment analysis (DEA) (Seydel, 2006; Saen, 2007), fuzzy set theory (Florez-Lopez, 2005; Sarkar and Mohapatra, 2006), genetic algorithm (GA) (Ding et al., 2005), mathematical programming (Wadhwa and Ravindran, 2007), and their hybrids (Wang and Lee, 2010), among which, DEA is a nonparametric method used in performance evaluation but sometimes encounters low discrimination problems (Lee et al., 2011; Lee and Zhu, 2012; Fang et al., 2013; Hwang et al., 2013). The methodologies based on fuzzy set theory have the merit that imprecise decision can be incorporated into the decision process. However, the membership function of the traditional fuzzy number is a crisp number. To remove such limit so that vagueness can be expressed more accurately, we propose a new fuzzy method based on interval-valued fuzzy numbers to rank potential candidates of the suppliers.

Ho et al. (2010) survey the multi-criteria supplier evaluation and selection approaches through a literature review and classification of the international journal articles from 2000 to 2008. Three issues are examined by Ho et al. (2010), including (i) Which approaches were prevalently applied? (ii) Which evaluating criteria were paid more attention to? (iii) Is there any inadequacy of the approaches? Ho et al. (2010) reveal that the most popular criteria is quality, followed by delivery, price/
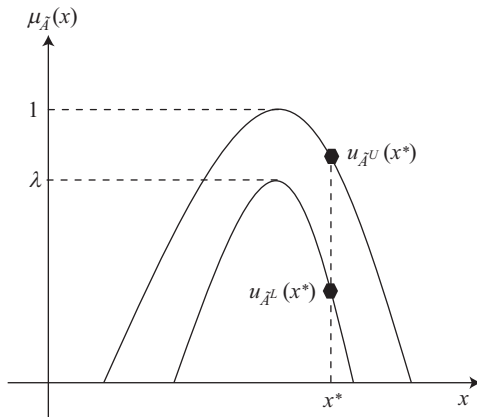
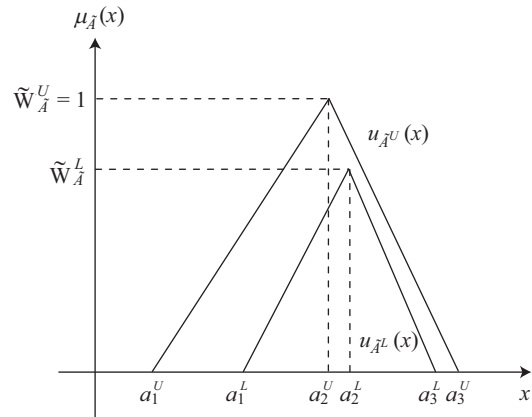**Fig. 1. Interval-valued fuzzy set $\tilde{A}$.**

Fig. 2. A triangular interval-valued fuzzy number.

cost, manufacturing capability, service, management, technology, research and development, finance, flexibility, reputation, relationship, risk, and safety and environment. Therefore, in our empirical example, we adopt five of these criteria as the evaluation criteria. They are cost, quality, delivery, flexibility and service respectively.

Since fuzzy set theory is one of the most popular approaches for supplier selection as noted in Ho et al. (2010). In this paper, we propose a fuzzy multiple criteria decision making model to facilitate supplier selection in supply chain management, especially in the electronic marketplaces today. To deal with vagueness and imprecision during assessment process more precisely, the concept of the interval-valued fuzzy numbers is introduced.

The paper is organized as follows: Section 2 introduces the interval-valued fuzzy numbers. Section 3 presents the extended fuzzy preference relation based on the interval-valued fuzzy numbers. Section 4 presents the proposed ranking algorithm for the suppliers under evaluation. An empirical example of the textile industry is presented in Section 5, and finally, concluding remarks are made in Section 6.

II. INTERVAL-VALUED FUZZY NUMBERS

In this paper, we treat all imprecise information as interval-valued fuzzy numbers. Based on the definition of interval-valued fuzzy numbers in (Gorzalczany, 1987), an interval-valued fuzzy number is defined as

$$\tilde{A} = \{x, [\mu_{\tilde{A}^L}(x), \mu_{\tilde{A}^U}(x)]\}, x \in (-\infty, \infty),$$

$$\mu_{\tilde{A}^L}, \mu_{\tilde{A}^U} : (-\infty, \infty) \rightarrow [0,1],$$

$$\mu_{\tilde{A}^L} \leq \mu_{\tilde{A}^U}, \forall x \in (-\infty, \infty),$$

$$\mu_{\tilde{A}}(x) = [\mu_{\tilde{A}^L}(x), \mu_{\tilde{A}^U}(x)], x \in (-\infty, \infty),$$

where $\mu_{\tilde{A}^L}(x)$ is the lower limit of the degree of membership and is the upper limit of the degree of membership. A interval-valued fuzzy number is shown in Fig. 1, which shows that the

degree of membership at x^* is in the interval $[\mu_{\tilde{A}^L}(x^*), \mu_{\tilde{A}^U}(x^*)]$.

Yao and Lin (2002) define the triangular interval-valued fuzzy number $\tilde{A}$ to be represented by two fuzzy numbers $\tilde{A}_x^L = (a_1^L, a_2^L, a_3^L; \tilde{w}_{\tilde{A}}^L)$ and $\tilde{A}_x^U = (a_1^U, a_2^U, a_3^U; \tilde{w}_{\tilde{A}}^U)$:

$$\tilde{A} = [\tilde{A}_x^L, \tilde{A}_x^U]$$
$$= [(a_1^L, a_2^L, a_3^L; \tilde{w}_{\tilde{A}}^L), (a_1^U, a_2^U, a_3^U; \tilde{w}_{\tilde{A}}^U)]$$

satisfying that $a_1^U \leq a_1^L$, $a_3^L \leq a_3^U$ and $\tilde{w}_{\tilde{A}}^L \leq \tilde{w}_{\tilde{A}}^U$ where $\tilde{w}_{\tilde{A}}^U$ and $\tilde{w}_{\tilde{A}}^L$ are the heights of $\tilde{A}_x^U$ and $\tilde{A}_x^U$. The graphical representation for a triangular interval-valued fuzzy number is shown in Fig. 2.

Usually to facilitate computation, a more restricted triangular interval-valued fuzzy number is adopted in real applications, where $a_2^L = a_2^U$ and $\tilde{w}_{\tilde{A}}^L = \tilde{w}_{\tilde{A}}^U = 1$. In this paper, we provide a formal definition for this restricted triangular interval-valued fuzzy number.

Definition 1. A normal triangular interval-valued fuzzy number A is a triangular interval-valued fuzzy number happens to $a_2^L = a_2^U$ and $\tilde{w}_{\tilde{A}}^L = \tilde{w}_{\tilde{A}}^U = 1$. Let $a_2 = a_2^L = a_2^U$. Then a normal triangular interval-valued fuzzy number A can be represented by $A = (A^L, A^U) = ((a_1^L, a_2^L, a_3^L), (a_1^U, a_2^U, a_3^U)) = (a_1^U, a_1^L, a_2, a_3^L, a_3^U)$ as shown in Fig. 3.

Given two normal triangular interval-valued fuzzy numbers A and B, the arithmetic operations of A and B are as follows (Chen, 1997; Hong and Lee, 2002; Chen and Chen, 2008):

(1) Addition of two normal triangular interval-valued fuzzy numbers:

$$A \oplus B = (a_1^U, a_1^L, a_2, a_3^L, a_3^U) \oplus (b_1^U, b_1^L, b_2, b_3^L, b_3^U)$$
$$= (a_1^U + b_1^U, a_1^L + b_1^L, a_2 + b_2, a_3^L + b_3^L, a_3^U + b_3^U)$$
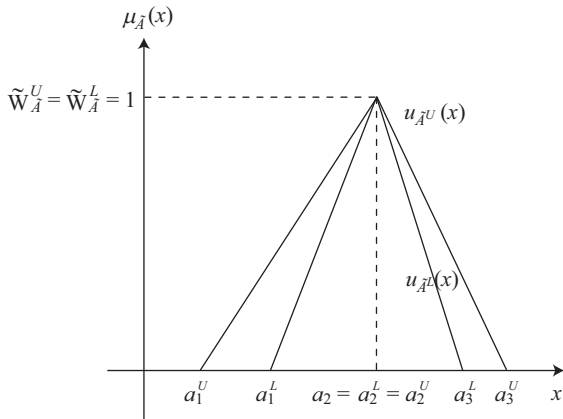
Fig. 3. A normal triangular interval-valued fuzzy number.

(2) Subtraction of two normal triangular interval-valued fuzzy numbers:

$$A \ominus B = (a_1^U, a_1^L, a_2, a_3^L, a_3^U) \ominus (b_1^U, b_1^L, b_2, b_3^L, b_3^U)$$
$$= (a_1^U - b_3^U, a_1^L - b_3^L, a_2 - b_2, a_3^L - b_1^L, a_3^U - b_1^U)$$

(3) Multiplication of two normal triangular interval-valued fuzzy numbers:

$$A \otimes B = (a_1^U, a_1^L, a_2, a_3^L, a_3^U) \otimes (b_1^U, b_1^L, b_2, b_3^L, b_3^U)$$
$$= (a_1^U \times b_1^U, a_1^L \times b_1^L, a_2 \times b_2, a_3^L \times b_3^L, a_3^U \times b_3^U)$$

(4) Division of two normal triangular interval-valued fuzzy numbers:

$$A \phi B = (a_1^U, a_1^L, a_2, a_3^L, a_3^U) \phi (b_1^U, b_1^L, b_2, b_3^L, b_3^U)$$
$$= (a_1^U / b_3^U, a_1^L / b_3^L, a_2 / b_2, a_3^L / b_1^L, a_3^U / b_1^U)$$

III. EXTENDED FUZZY PREFERENCE RELATIONS

In this section, we will develop an extended fuzzy pre-ference relation for normal triangular interval-valued fuzzy numbers, which measure the preference degree of one fuzzy number over the other one.

Definition 2. Let G be a fuzzy number. Then the α-cut of G, (G_α^L, G_α^U), is defined by $G_\alpha^L = \inf_{\mu_G(z) \geq \alpha}(z)$ and $G_\alpha^U = \sup_{\mu_G(z) \geq \alpha}(z)$.

Definition 3. Let $A = (A^L, A^U) = ((a_1^L, a_2^L, a_3^L), (a_1^U, a_2^U, a_3^U)) = (a_1^U, a_1^L, a_2, a_3^L, a_3^U)$ be a normal triangular interval-valued fuzzy number. Then α-cut of A, $A^\alpha = (A_\alpha^L, A_\alpha^U)$, is defined in terms of the α-cut of the fuzzy numbers of A^L and A^U. The α-cut of A^L, $A^{L\alpha} = (A_\alpha^{LL}, A_\alpha^{LU})$, is given by $A_\alpha^{LL} =$

$\inf_{\mu_{A^L}(z) \geq \alpha}(z)$ and $A_\alpha^{LU} = \sup_{\mu_{A^L}(z) \geq \alpha}(z)$. The α-cut of A^U, $A^{U\alpha} = (A_\alpha^{UL}, A_\alpha^{UU})$, is given by $A_\alpha^{UL} = \inf_{\mu_{A^U}(z) \geq \alpha}(z)$ and $A_\alpha^{UU} = \sup_{\mu_{A^U}(z) \geq \alpha}(z)$. Hence the α-cut of A, $A^\alpha = (A_\alpha^L, A_\alpha^U) = ((A_\alpha^{LL}, A_\alpha^{LU}), (A_\alpha^{UL}, A_\alpha^{UU})) = (A_\alpha^{UL}, A_\alpha^{LL}, A_\alpha^{LU}, A_\alpha^{UU})$.

Definition 4. An extended fuzzy preference relation R on normal triangular interval-valued fuzzy numbers is an extended fuzzy subset of the product of normal triangular interval-valued fuzzy numbers with membership function $-\infty \leq \mu_R(A, B) \leq \infty$ being the preference degree of the normal triangular interval-valued fuzzy number A over the number B.

Definition 5. The preference relation R is reciprocal if and only if $\mu_R(A, B) = -\mu_R(B, A)$ for all normal triangular inter-valued fuzzy numbers A and B.

Definition 6. The preference relation R is transitive if and only if $\mu_R(A, B) \geq 0$ and $\mu_R(B, C) \geq 0$ imply that $\mu_R(A, C) \geq 0$ for all normal triangular inter-valued fuzzy numbers A, B and C.

Definition 7. The preference relation R is additive if and only if $\mu_R(A, C) = \mu_R(A, B) \oplus \mu_R(B, C)$ for all normal triangular inter-valued fuzzy numbers A, B and C.

Definition 8. The preference relation R is a total ordering if and only if R is reciprocal, transitive and additive.

Let A_m denote the triangular fuzzy number obtained by ave-raging the lower triangular fuzzy number and upper triangular fuzzy number of a normal triangular interval-valued fuzzy number $A = (A^L, A^R)$: $A_m = (A^L \oplus A^R)/2$.

Definition 9. For any normal triangular interval-valued fuzzy numbers A and B, we define the extended fuzzy preference relation $R(A, B)$ by the membership function:

$$\mu_R(A, B) = \int_0^1 ((A \ominus B)_{m\alpha}^L + (A \ominus B)_{m\alpha}^U)/2 \, d\alpha$$

It is easy to show that R is reciprocal, additive and transitive. If $R(A, B)$, we say that A and B have the same preference. If $R(A, B) > 0$, we prefer A to B and vice versa.

IV. RANKING ALGORITHM

Assume there m suppliers under evaluation against n criteria. Let the normal triangular interval-valued fuzzy number A_{ij} be the rating of the i-th supplier under j-th criterion and the normal triangular interval-valued fuzzy number W_j be the weight of the j-th criterion. We define the preference intensity function of one normal triangular interval-valued

number A over another number B as follows:

$$Q(A, B) = \max\{\mu_R(A, B), 0\}.$$

Let J be the set of the benefit criteria and J' be the set of the cost criteria where

$$J = \{1 \le j \le n \text{ and } j \text{ belongs to the benefit criteria}\}$$

$$J' = \{1 \le j \le n \text{ and } j \text{ belongs to the cost criteria}\},$$

and

$$J \cup J' = \{1, \ldots, n\}.$$

By the benefit criteria, we mean that the larger their value is and the better the supplier, whereas the cost criteria are on the contrary. The advantage of the i-th supplier under j-th criterion is given by

$$a_{ij} = \begin{cases} \sum_{k \ne i} Q(W_j A_{ij}, W_j A_{kj}) & \text{if } j \in J \\ \sum_{k \ne i} Q(W_j A_{kj}, W_j A_{ij}) & \text{if } j \in J' \end{cases} \quad (1)$$

Likewise, we define the disadvantage of i-th supplier under j-th criterion is given by

$$d_{ij} = \begin{cases} \sum_{k \ne i} Q(W_j A_{kj}, W_j A_{ij}) & \text{if } j \in J \\ \sum_{k \ne i} Q(W_j A_{ij}, W_j A_{kj}) & \text{if } j \in J' \end{cases} \quad (2)$$

Note that both a_{ij} and d_{ij} are crisp numbers. The superiority of the i-th supplier is given by

$$S_i = \sum_{j=1}^{n} a_{ij} \quad (3)$$

The inferiority of the i-th supplier is given by

$$I_i = \sum_{j=1}^{n} d_{ij} \quad (4)$$

The composite index for the i-th supplier is given by

$$C_i = \frac{S_i}{S_i + I_i} \quad (5)$$

The evaluation algorithm for suppliers is outlined as follows and its flow chart is depicted in Fig. 4.
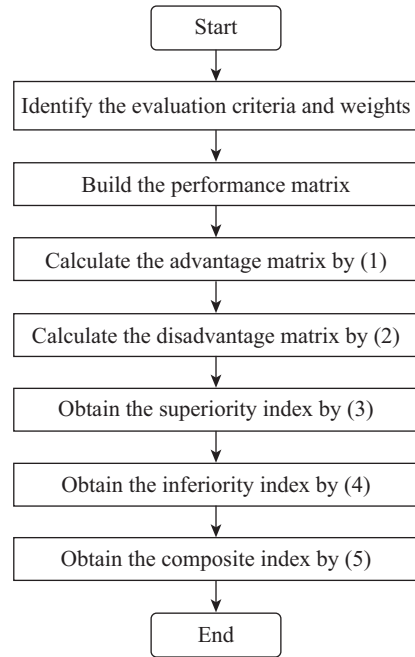

Fig. 4. Flow chart of the algorithm.

Supplier evaluation algorithm:

Step 1. Identify the evaluation criteria for suppliers and its corresponding weight W_j, $j = 1, \ldots, n$.

Step 2. Build up the performance matrix $[A_{ij}]_{m \times n}$, where A_{ij} is a normal triangular interval-valued fuzzy number denoting the rating of the i-th supplier under j-th criterion.

Step 3. Calculate the advantage matrix $[a_{ij}]_{m \times n}$, where a_{ij} denotes the advantage of the i-th supplier under j-th criterion given by (1).

Step 4. Calculate the disadvantage matrix $[d_{ij}]_{m \times n}$, where d_{ij} denotes the disadvantage of the i-th supplier under j-th criterion given by (2).

Step 5. Obtain the superiority index S_i for the i-th supplier given by (3).

Step 6. Obtain the inferiority index I_i for the i-th supplier given by (4).

Step 7. Obtain the composite index C_i for each supplier by (5) and rank all supplier according to the composite indices obtained.

V. EMPIRICAL EXAMPLE

Textile is one of the important sectors of the traditional industries in Taiwan. For many years, Taiwan's textile and apparel manufacturers struggled to overcome the twin hurdles of changing global market conditions and the widely held perception they were on their way toward the scrapheap of history. But R.O.C. government support, coupled with the development of an array of exciting products, has brought these firms back from the brink, repositioning them for what many believe will be the dawn of a long-term era of niche market dominance.

Table 1. Linguistic variables and their corresponding normal triangular interval-valued fuzzy numbers.

Very Poor	Very Low	(0,0,0,0.5,1)
Poor	Low	(0,0.5,1,2,3)
Medium Poor	Medium Low	(1,2,3,4,5)
Fair	Fair	(3,4,5,6,7)
Medium Good	Medium High	(5,6,7,8,9)
Good	High	(7,8,9,9.5,10)
Very Good	Very High	(9,9.5,10,10,10)

Table 2. Weights of criteria.

	C1 (Cost)	C2 (Quality)	C3 (Delivery)	C4 (Flexibility)	C5 (Service)
Weight	Very High	High	Very High	High	High

Table 3. Performance matrix of the suppliers.

	C1	C2	C3	C4	C5
Supplier 1	High	Good	Very Good	Good	Fair
Supplier 2	Low	Very Good	Good	Good	Good
Supplier 3	Fair	Medium Good	Good	Fair	Good

Table 4. The advantage matrix for the suppliers.

	C1	C2	C3	C4	C5
Supplier 1	0	11.52083	11.6875	23.27083	0
Supplier 2	74.95833	21.64583	0	22.27083	22.7083
Supplier 3	24.91667	0	0	0	18.60471

Table 5. The disadvantage matrix for the suppliers.

	C1	C2	C3	C4	C5
Supplier 1	74.85417	5.5625	0	0	40.875
Supplier 2	0	0	6.4375	0	6.4375
Supplier 3	25.02083	27.60417	5.25	45.54167	103.4167

Table 6. The superiority indices for the suppliers.

Supplier	Superiority index
Supplier 1	46.47917
Supplier 2	141.1458
Supplier 3	43.52083

Table 7. The inferiority indices for the suppliers.

Supplier	Inferiority index
Supplier 1	121.2917
Supplier 2	6.4375
Supplier 3	103.4167

Table 8. The composite performance indices for the suppliers.

Supplier	Composite performance index
Supplier 1	0.27704
Supplier 2	0.956381
Supplier 3	0.296186

A textile company to be competitive has to be not only innovative but also cost down. Inbound logistic plays an important role in reducing the cost and producing quality product. One textile company desires to select suitable suppliers to purchase yarn for a new product. A committee of decision makers, D1, D2 and D3 has been constituted and then committee selected Price (C1), Quality (C2), Delivery (C3), Flexibility (C4), and Service (C5) as selection criteria, among which C1 is a cost criterion, which means the smaller the better, whereas C2, C3, C4 and C5 are benefit criteria, which means the larger the better. Three supplier candidates, A1, A2 and A3, are under consideration. The linguistic variables employed and their corresponding fuzzy numbers are shown in Table 1. The whole evaluation process with our algorithm is as follows:

Step 1. The evaluation criteria identified and their weights are shown in Table 2.
Step 2. The performance matrix of the suppliers is shown in Table 3. The table indicates that the cost (C1) of the second supplier is "Low" and his/her quality is "Very Good".
Step 3. According to Eq. (1), the advantages of the suppliers can be computed. The advantages of the suppliers under each criterion are shown in Table 4. For example, the first supplier has no advantage under criterion 1 but he/she has advantage 23.27083 under criterion 4.
Step 4. According to Eq. (2), the disadvantage of the su-ppliers can be computed. The disadvantages of the suppliers under each criterion are shown in Table 5. For example, the second supplier has no disadvantage under criterion 1 but he/she has disadvantage 6.4375 under criterion 3.

Step 5. The superiority index for each supplier can be obtained according to Eq. (3). The superiority indices for the suppliers are shown in Table 6.
Step 6. The inferiority index for each supplier can be obtained according to Eq. (4). The inferiority indices for the suppliers are shown in Table 7.
Step 7. According Eq. (5), the composite performance index for each supplier can be obtained. The composite performance indices for the suppliers are shown in Table 8. It indicates that the second supplier is the most appropriate supplier under evaluation.

VI. CONCLUSIONS

As globalization and competition increases, procurement function becomes a critical activity for firms to succeed in global arena. Within this perspective, supplier selection plays a

key role for firms in achieving the objectives of the supply chain management. Moreover, selecting appropriate method and criteria constructs the core structure to select best supplier among candidates.

The current paper develops a new fuzzy multiple criteria decision making model to evaluate the suppliers so that vagueness and imprecision can be introduced during assessment. Evaluation committee can assess the suppliers with linguistic variables such as "Very good", "Fair" and "Poor" etc. Our model then represents these linguistic variables in terms of the normal triangular interval-valued fuzzy numbers, which grasp the vagueness more precisely than triangular fuzzy numbers. Arithmetic manipulations of the normal triangular interval-valued fuzzy numbers have been developed. We also develop a mechanism to compare to normal triangular interval-valued fuzzy numbers. The model proposed can be implemented as an evaluation agent in an e-marketplace to assist customers in the decision making of the supplier selection problem so that procurement can be automated.

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