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MULTI-ATTRIBUTE DECISION MAKING FOR MODELING SUPPLIER SELECTION OF E-PROCUREMENT

Yanning Guo, Yi Qu* and Yanzhang Wang

Faculty of Management and Economics
Dalian University of Technology
No. 2, Linggong Road, Ganjingzi District, Dalian 116024, P. R. China
guoyanningdlut@163.com; yzwang@dlut.edu.cn
*Corresponding author: shuijingnm16@163.com

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Abstract. *As the implementation and development of e-procurement in government, as well as the openness of government procurement, more small and medium-sized enterprises (SMEs) become candidate suppliers of the e-procurement. Therefore, it is essential for government to select an appropriate supplier. The government procurement has the non-profit characteristic, which is different from business procurement. By introducing the egalitarian social welfare attribute in the area of auction, this paper proposes a new multi-attribute decision making method to select a dominated supplier with the consideration of government procurement feature. The government preference is also taken into account through the weight vector. The payment mechanism in the proposed method is based on the incentive compatible principle, which can encourage companies to tell their true value of attributes and protect the government profit from decreasing because of companies' dishonesty. Numerical examples are provided and their results demonstrate that this novel method provides a flexible and effective way for the government's supplier selection.*

Keywords: Supplier selection, Government procurement, Multi-attribute decision making, Egalitarian social welfare

1. **Introduction.** E-procurement is a blend of two frontiers: e-government and e-commerce. Because of efficiency, transparency, standardization and economy, e-procurement attracts more and more attention. With the implementation and development of e-procurement, as well as the openness of government procurement, more small and medium-sized enterprises (SMEs) become candidate suppliers of the e-procurement. The purpose of government's procurement activities is not for profit, but to regulate the balance of economics, facilitate fair competition in the industry and improve the social welfare. This is different from business procurement. Therefore, except for the price, the non-profit characteristic of e-procurement should be considered into the selection of suppliers [1]. So how to choose a reasonable supplier from multitudinous SMEs under the consideration of government procurement features is not only of important theoretical value but also of practical significance.

Supplier selection is a multi-attribute decision making (MADM) [2] process. In previous studies, numerous quantitative and qualitative methods are used for supplier selection, including analytic hierarchy process (AHP) [3,4], TOPSIS [5,6], and data envelopment analysis [7,8]. However, those methods are mainly applied in business procurement. Thus, this research takes the trait of non-profit procurement into consideration by introducing the egalitarian social welfare (ESW) attribute in the area of auction [9,10]. In addition, the information asymmetry between SMEs and government may cause some enterprises to provide false information. In order to encourage enterprises to provide true information, the payment in the proposed model considers the incentive compatibility.

This paper is organized as follows. Section 2 gives problem description. Section 3 develops the supplier selection model. Section 4 provides numerical examples and results analysis. The paper is concluded in Section 5.

2. **Problem Description.** Assuming the government need purchase a certain kind of consumables, and this kind of consumables has been purchased through the way of e-procurement. The government will announce the procurement information and post it on the website of e-procurement. The requirements of suppliers can be expressed by attribute sets $C^r : ct_1^r \in D_1^r, \ldots, ct_{m_r}^r \in D_{m_r}^r$, where D_i^r refer to the range of attribute ct_i^r. If a supplier decides to participate in this procurement, it will submit its attributes to the government. Due to the existence of information asymmetry, the government is not sure about the authenticity of some attributes, such as price. Those attributes are called unknown attributes $C^u : ct_1^u, \ldots, ct_{m_u}^u$. The other attributes can be verified by the government, such as delivery time, and they are expressed by $C^v : ct_1^v, \ldots, ct_{m_v}^v$. To reduce the complexity of calculation, this paper only considers one unknown attribute $C^u : p$, where p is the price of purchasing item. When the government receives suppliers' attribute sets, it will add ESW attribute s_i to suppliers' attribute sets. Equation (1) is the calculation of ESW attribute.

$$s_i : 1 - \frac{1 + win_i}{1 + participated_i} \tag{1}$$

The parameter win_i and $participated_i$ are the winning times and participated times in a time window (the decision maker can select a specific time window), respectively. Based on the weight vector $\mathrm{W} = (w_1, w_2, \ldots, w_{m_r}, w_{s_i})$, the changed attributes sets can be used to calculate the ranking order of suppliers. And then select the best supplier to cooperate.

However, some suppliers may lie about their attributes in order to be selected. So the incentive compatibility is introduced in the proposed model to protect government benefit from dishonest suppliers and encourage suppliers to provide true attributes. The following section will give the detail of the proposed model.

3. **Supplier Selection Model.** According to problem description, this proposed model includes four steps: Announce Procurement, Submit Information, Choose Winner and Pay to the Winner. Figure 1 illustrates an overview of this model.

(1) Announce Procurement. The government announces a procurement on the website of e-government. The attribute set can be extracted from the requirements and denoted by AS_{ID}:

$$\mathrm{AS}_{ID} =< \mathrm{as}_{ID}, (ct_1^r, R_1^r), \ldots, (ct_{m_r}^r, R_{m_r}^r) > \tag{2}$$

where R_i^r is the subset of D_i^r, and m_r is the total number of attributes. For example, $< as0, (cost, [5, 10]), (delivery\ time, [1, 5]) >$ means the price should be between 5 and 10, while delivery time should be between 1 and 5.

(2) Submit Information. Suppliers will submit information to the government based on attribute set and their own condition. The attribute set of supplier i can be represented by A_i.

$$A_i = C_i^u \oplus C_i^v = \left(p_i, ct_{1i}^v, \ldots, ct_{m_v i}^v\right) \tag{3}$$

However, some suppliers may provide false information in order to win. For example, a supplier can deliver the procurement in 4 days under the cost of 7, but it may submit $< as1, (cost, 5), (delivery\ time, 4) >$. The valuation $v_i(C_i^v)$ is equal to unknown attribute p_i when a supplier submits true information.

$$v_i(C_i^v) = C_i^u \tag{4}$$

If a supplier is dishonest, then:

$$v_i(C_i^v) \neq C_i^u \tag{5}$$

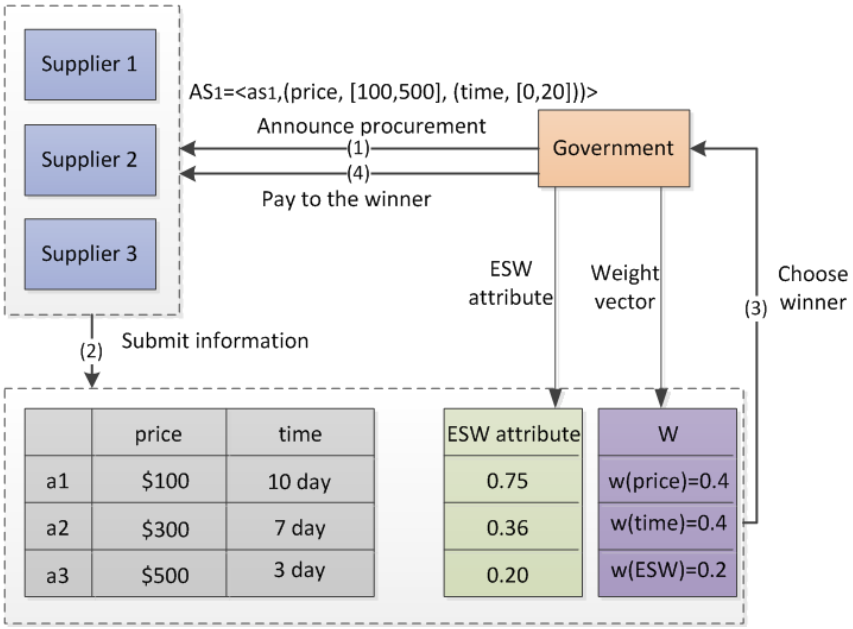

FIGURE 1. An example based on the proposed model

(3) Choose Winner. Based on suppliers attribute sets, ESW attribute and weight vector, the government ranks suppliers using evaluation function and chooses the top one as the winner. Specific processes are as follows: firstly, the government will extend each attribute set with ESW attribute. The extended attribute set is represented by A_i':

$$A_i' = \left(ct_i^u, ct_{1i}^v, \ldots, ct_{m_v i}^v, s_i\right) \tag{6}$$

Secondly, assuming that the government is risk-neutral, the utility of government can be derived:

$$u_0(A_i') = v_0(A_i') - P = v_0\left(C_i^u, C_i^v, s_i\right) - P \tag{7}$$

$$v_0(A_i') = w_1 f_1(p_i) + \sum_{j=2}^{m_v} w_j f_j(ct_{ji}^v) + w_s f_s(s_i) \tag{8}$$

where $v_0(C_i^v)$ denotes weighted sum of valuation for supplier i's attribute set A_i'; P is the payment to winner; $f_j(\cdot)$ or $f_s(\cdot)$ denotes evaluation function for each attribute and it should satisfy a set of conditions [11]. Meanwhile, attributes in MADM are usually divided into cost attribute and benefit attribute [12]. In this paper, evaluation functions are classified into two types: cost attribute and benefit attribute. The value of $f(x)$ decreases with the increase of cost attribute, which is represented by negative exponential function:

$$f(x) = \alpha_c - \mu_c \beta_c^{\gamma x}, \quad \mu_c, \gamma > 0,\ \beta_c > 1,\ f(x) \le 0 \tag{9}$$

where α_c, μ_c, β_c and γ are the parameters of negative exponential function, and they are given by decision makers. Whereas, the value of $f(x)$ increases with the increase of benefit attribute, which is represented by positive exponential function:

$$f(x) = \alpha_b - \mu_b \beta_b^{-\delta x}, \quad \alpha_b, \mu_b, \delta > 0,\ \beta_b > 1,\ f(x) > 0 \tag{10}$$

where α_b, μ_b, β_b and δ are the parameters of positive exponential function.

Finally, the objective is to maximize utility of government. It can be denoted by the following equation:

$$\arg\max_{i>0}\left(u_0(x, A_i')\right) \tag{11}$$

The payment P is identical for each supplier, so the objective can be replaced by Equation (12).

$$\arg\max_{i>0}\left(v_0(A_i')\right) \tag{12}$$

(4) Pay to the Winner. In order to motivate suppliers to submit their true value of attribute sets, this paper introduces the payment of incentive compatible second bid auction. So, the winner will receive the second-best supplier offered cost:

$$P = f_1^{-1} = \left(\frac{\mathrm{w}_1 f_1(p_2) + \sum_{j=2}^{m_v} \left(\mathrm{w}_j f_j(ct_{j2}^v) - \mathrm{w}_j f_j(ct_{ji}^v) \right) + \mathrm{w}_s f_s(s_2) - \mathrm{w}_s f_s(s_i)}{\mathrm{w}_1} \right) \quad (13)$$

However, if the winner cannot achieve what it says, the payment will become:

$$P = f_1^{-1} = \left(\frac{\mathrm{w}_1 f_1(p_i) + \sum_{j=2}^{m_v} \left(\mathrm{w}_j f_j(ct_{ji}^{v'}) - \mathrm{w}_j f_j(ct_{ji}^v) \right) + \mathrm{w}_s f_s(s_i) - \mathrm{w}_s f_s(s_i)}{\mathrm{w}_1} \right) \quad (14)$$

where $ct_{ji}^{v'}$ are the true values of attributes.

4. **Numerical Examples.** To demonstrate the flexibility and effectiveness of this proposed model, numerical examples of the proposed model are provided in this section.

The government purchased one type of consumables in the past year and it will purchase this consumable again. By incorporating green index into the government procurement, suppliers' products should meet the requirement of environmental protection standards. Meanwhile, the unit price pr ranges from 10 to 20 dollars; the quality of this consumable q must be above-average; and delivery must be effected within 4 days. Thus, the requirements can be denoted by attribute set AS_{21}:

$$\mathrm{AS}_{21} =< as_{21}, (pr, [10, 20]), (q, [0.5, 1]), (t, [1, 4]) > \quad (15)$$

After the announcement of procurement, suppliers who want to participate will submit their attribute sets to the government. The government will weed out suppliers that fail to meet the basic qualifications. Suppose that there are six qualified suppliers $a_i \in \{a_1, a_2, a_3, a_4, a_5, a_6\}$, as shown in Table 1. And the ESW attribute s_i of each qualified supplier is calculated by Equation (1). Based on the weight vector $W_1 = (0.3, 0.5, 0.1, 0.1)$, which represents the government preference, the value of $v_0(A_i')$ can be calculated according to Equations (9)-(11). As pr and t are cost attribute, their evaluation functions are set to $f(pr) = -2^{0.1*pr}$ and $f(t) = -2 - 0.1 * 2^t$. While q and s are benefit attribute, their evaluation functions are set to $f(q) = 50 - 16 * 2^{-4*q}$ and $f(s) = 30 - 16 * 2^{-4*s}$. The ranking order (RO 1) is shown in Table 1.

Table 1. Suppliers attribute sets and ranking orders

AS	$\boldsymbol{C^u}$	$\boldsymbol{C^v}$		$\boldsymbol{s_i}$	$v_0(A_i')$	RO 1	RO 2
	p_i	q_i	t_i				
a_1	10	0.52	2	0.80	25.09	6	6
a_2	11	0.62	2	0.78	25.50	5	5
a_3	14	0.68	3	0.75	25.51	4	4
a_4	15	0.73	2	0.90	25.72	2	3
$\boldsymbol{a_5}$	**18**	**0.85**	**3**	**0.83**	**25.76**	**1**	**1**
a_6	19	0.91	4	0.76	25.68	3	2

Dishonesty analysis. In the above ranking order, supplier a_5 will be chosen by the government. According to Equation (13), the government will pay $P = 18.47$ to a_5 if it accomplishes this procurement as it says. And the government's utility will be $u_0 = 25.76 - 18.47 = 7.29$. However, if this supplier only can provide the product quality of 0.85 within 4 days, then government will pay $P = 16.85$ and government's utility will be $u_0 = 25.68 - 16.85 = 8.83$. Considering the above analysis, it is evident that the winner will gain less and the proposed payment can protect government's benefit from dishonest suppliers.

ESW attribute and preferences analysis. If the ESW attribute is not considered, the ranking order RO 2 is shown in Table 1. In this numerical example, the winner is a_5, too. However, a_6, rather than a_4, is ranked as the second supplier. Therefore, the payment P will change. In addition, if another set of attribute sets is taken, the winner of this procurement will probably not be the same one. Above all, ESW attribute has a significant impact on the results.

The weights of attributes reflect the decision maker's preference. Ranking orders are different under different preferences. In this research, three types of preferences are considered and their ranking orders are presented in Table 2. Results show that when the government concerns more about product quality (or price), it will choose suppliers whose quality (price) is high (low). However, when the government preference is not obvious, like W_3, it will choose suppliers whose all attributes are relatively well. Thus, the government should deliberate on the weight vector W before selecting suppliers.

TABLE 2. The ranking orders of different preferences

	$W_1 = (0.3, 0.5, 0.1, 0.1)$		$W_2 = (0.3, 0.5, 0.1, 0.1)$		$W_3 = (0.3, 0.3, 0.2, 0.2)$	
	$v_0(A_i')$	RO 1	$v_0(A_i')$	RO 3	$v_0(A_i')$	RO 4
a_1	25.09	6	15.45	4	18.44	5
a_2	25.50	5	**15.64**	**1**	18.65	2
a_3	25.51	4	15.47	3	18.52	4
a_4	25.72	2	15.58	2	**18.77**	**1**
a_5	**25.76**	**1**	15.36	5	18.62	3
a_6	25.68	3	15.19	6	18.39	6

5. **Conclusions.** To select a reasonable supplier from multitudinous SMEs under the consideration of government preference and government procurement features is not only of academic significance but also of practical value. In this paper, the multi-attribute decision making model is founded to solve the supplier selection of e-government. This model takes the ESW attribute into consideration in order to deal with the non-profit characteristics of government procurement. On this basis, the incentive compatibility is introduced into the payment. The results show that the ESW attribute and weight vector have an important influence on supplier selection. Thus, the government should deliberate on those two factors before selecting suppliers. All in all, this model gives a flexible and effective way to solve the complicated supplier selection problem.

This model presented in this paper does not take all relevant factors into consideration, such as the environmental factors of government procurement. The green procurement has become a research hotspot. So, it will be the next study focus.

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