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Outcome-based Contractors Selection using the Integrated Fuzzy AHP and Fuzzy TOPISIS Method

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Abstract

Based on the concept of outcome-based maintenance, the outcome-based contractor equipment support is proposed as the logistical support strategy in the military industry. The outcome-based contractor equipment support is focus on the combat efficiency rather than on the performance of the equipments. Choosing the right contractor is a very important part in the process of its implementation. In fact, the contractor selection is a multi-criteria decision-making problem, which is largely dependent on the uncertainty and ambiguity of the decision-makers. This paper presents a systematic decision-making process of the outcome-based contractor selection, which employs fuzzy AHP to determine the importance weights of each index and adopts fuzzy TOPSIS to obtain the performance ratings of the alternative contractors. Finally, the validity of this method is verified by a specific case.

Keywords*: outcome-based contract, contractor selection, multi-criteria decision making, fuzzy AHP, fuzzy TOPSIS*

1. Introduction

It is very important to select a proper contractor in defense industry due to the fact that improper contractor selection can negatively affect the overall logistic system. Selecting the appropriate contractor is a difficult and time-consuming procedure. For an effective evaluation, the decision-maker needs to analyze a large amount of data and consider many factors.

This paper suggests that outcome-based maintenance is a kind of efficient weapon system product support strategy. It does not focus on the performance of the equipments, but turns to the outcome of the maintenance, combat efficiency, and other indexes. It can effectively reduce costs and downtime for maintenance of the system to achieve the rapid response and effective monitoring. The concept is applied to the contractor support area, and the theoretical system of the outcome-based contractor support is built. However, this support mode puts forward more strict requirements of the contractors.

This paper aims to propose a systematic evaluation model to help the managers in defense industries select an optimal contractor. Selection of contractors is a multi-criteria decision making (MCDM) problem where many criteria should be considered in decision-making, which contains subjectivity, uncertainty and ambiguity in evaluation process [1]. Therefore, the proposed approach determines the importance weights of evaluation criteria by utilizing the fuzzy AHP method, and obtains the performance ratings of the alternatives in linguistic values by using the fuzzy TOPSIS.

The paper is organized as follows: Section 2 presents a briefly introduction of outcome-based contractor support and the implementation process. Section 3 builds the evaluation index system. Section 4 describes a two-phase methodology for outcome-based contractor

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selection based on fuzzy AHP & TOPSIS. After that, a numerical example study is presented to prove the validity of the proposed approach in section 5 and Section 6 presents the conclusions.

2. Outcome-based Contractor Support

Outcome-based contractor support is proposed through the application of the outcome-based maintenance concept and achieved through the signing of outcome-based contract. Traditional MRO (maintenance, repair and operating) contracts are designed under a MRO service level.

Traditional MRO contracts are always beneficial for the contractors, as long as once a specific device failed contractor maintenance activities can be carried out in order to obtain maintenance costs. There is no motivation for the contractor to ensure that the device can continue to function well, even in extreme cases. It can lead to poor quality of the equipment supplied by the contractor, due to the fact that the contractor want to earn higher maintenance costs after equipment failure. However, the outcome-based contract has changed this situation for two reasons. The first reason is that it is allowed to pay for the desired outcomes, rather than the activities or tasks involved in the provision of the equipment, which greatly improves the military initiative resistance. The other reason is the unique incentive and competitive mechanisms, through which a lot of potential economic benefits will be brought for the contractor. Overall, compared with the traditional contracts, outcome-based contract sets up a more equitable risk and incentives between the military and the contractors.

The Implementation of the outcome-based contract support includes the following steps, and the specific process is shown as Figure 1.

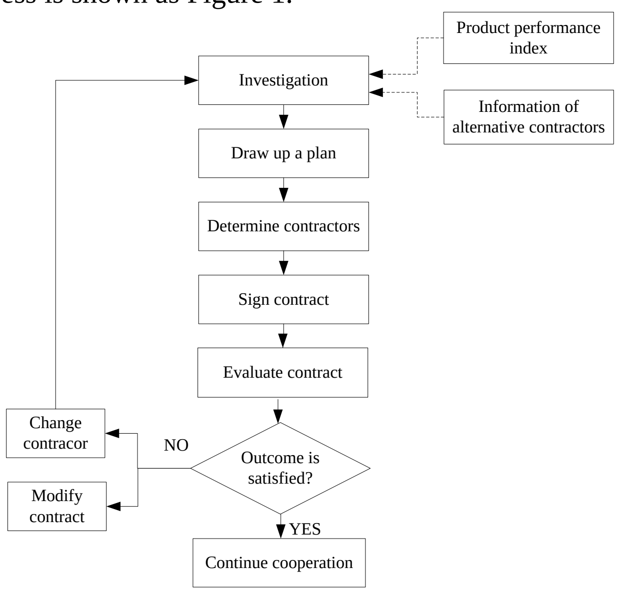

Figure 1. Implementation Process of Outcome-based Contract

Step 1: Investigation. Managers must determine the product performance index, and translate the demands into the contract design. On the other hand, they should collect much more information about the alternative contractors, such as cooperation ability, past performance, financial stability, and so on.

Step 2: Draw a plan. Sort out the information, Develop equipment requirement programs, draw a primary plan. Also invite public bidding to determine the group of the alternative contractors.

Step 3: Choose the best contractor. Build an evaluation criterion system and process to choose the most appropriate one from the alternative contractors group.

Step 4: Sign outcome-based contract. It should make clear the sharing of the tasks and responsibilities, especially to clear what specific “outcome” is, such as operational availability, reliability, and other indexes.

Step 5: Evaluate the support outcome. Evaluate the performance of the contractors comprehensively and regularly, and the military should play a leading role in the evaluation process. If the support outcome is good, it should continue or prolong the contract. If not good, then it should adjust or terminate the contract.

3. Evaluation Criteria System of Outcome-based Contractor Selection

A critical task in contractor selection process is to build a decision index system through which the capabilities of contractors are measured and assessed.

For the selection of contractor, there have been proposed a variety of evaluation criteria[3, 4]. But the selection index system construction of the outcome-based contract and the other forms of contractor selection system is quite different. The outcome-based contract has very strict requirements of the final outcomes, such as availability, reliability and other specific quantitative indexes. It also needs the cooperation between the military and contractor on resource sharing, information exchange, etc. The contract should be implemented within a certain cost and the appointed time. The selection criteria system and the index system must consider the following aspects:

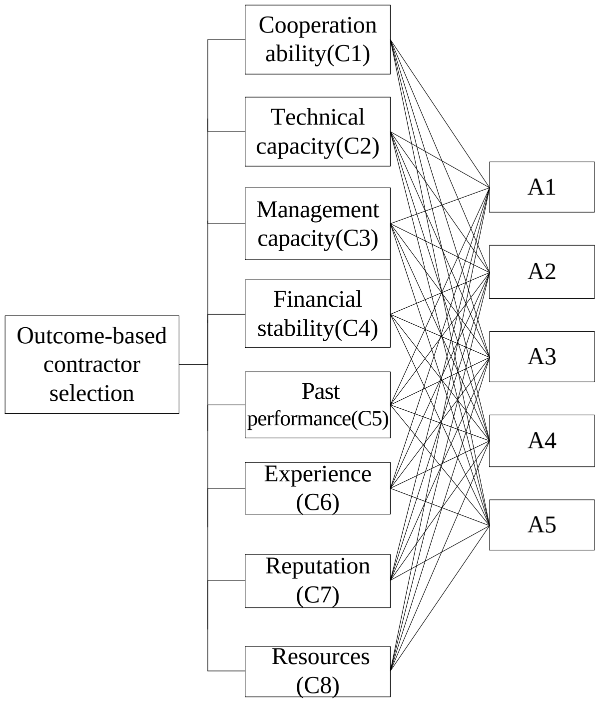

Figure 2. Outcome-based Contractor Selection Criteria System

(1) Cooperation ability: The contractor must have the ability to coordination and cooperation with the military and sub-contractors. If some problem happens, they can find assistance in a timely manner.

(2) Technical capacity: Contractor must prove that they have necessary technical capacity to fulfill the promise of the contract.

(3) Management capacity: It depends on whether there is an alternative contractor super management team, the relationship between rights and responsibilities, division of tasks must be clear. Also the contractor must demonstrate that it has the ability to plan, organize and control a project.

(4) Financial stability: The contractor must own a certain capital base, as the purchase of equipment, spare parts, components, software, etc., as well as the basic guarantee of resource scheduling.

(5) Past performance: The military can deliver products, such as quality, time and cost to assess their performance in accordance with the previous contractors.

(6) Experience: The contractor needs to provide the information about what projects they have completed, such as the type, the amount and ways they completed, especially whether they have executed the similar project.

(7) Reputation: The supervisor must have an objective and comprehensive understanding of the alternative contractors. The information can be obtained through other people or company, the records of the history, or other approaches.

(8) Resources: Whether contractors have enough necessary resources, including software resources and hardware resources.

4. Integrated Fuzzy AHP and Fuzzy TOPISIS Method

4.1 Formal Description of the Problem

In fact, outcome-based contractor selection is a group multiple-criteria decision-making problem, which can be stated by some sets as follows:

(1) Form the decision making committee, consisted of K experts and expressed by a set $E=\{D_1,D_2,...,D_K\}$, the importance weights of experts can be denoted by $\mathbf{w}_{\text{expert}}=\{w_1,w_2,...,w_K\}$;

(2) Determine m contractors as the alternatives, which can be expressed by a set $A=\{A_1,A_2,...,A_m\}$;

(3) Construct the evaluation criteria system which is consisted of n criteria, expressed by a set $C=\{C_1,C_2,...,C_n\}$.

4.2 Fuzzy AHP

Analytic hierarchy process (AHP) is a classic method to solve the complicated decision problems and widely used in solving with many decision-making problems[2] . Any complicated problem can be broken down into several sub-problems by AHP according to hierarchical levels. However, the traditional AHP method has some shortcomings[3, 4] . AHP uses an exact value to the decision-maker’s opinion and does not consider the uncertainty with human judgment to a number by linguistic. To overcome these shortcomings, the fuzzy AHP based on the trapezoidal fuzzy numbers was developed for solving with the uncertainty. The process makes it possible to combine qualitative criteria and quantitative criteria to make a comprehensive judgment.

Definition 1[5] ：A positive triangular fuzzy number (PTFN) $\tilde{A}$ can be defined as (l,m,u), and the membership function $\mu_{\tilde{A}}(x):\mathbb{R}\rightarrow[0,1]$ is defined as

$$\mu_{\tilde{A}}(x)=\begin{cases}\dfrac{x-l}{m-l}, & l\le x\le m\\ \dfrac{u-x}{u-m}, & m\le x\le u\\ 0, & otherwise\end{cases} \tag{1}$$

l and u mean the lower and upper bounds of the fuzzy number, and m is the middle value, as shown in Figure 3.

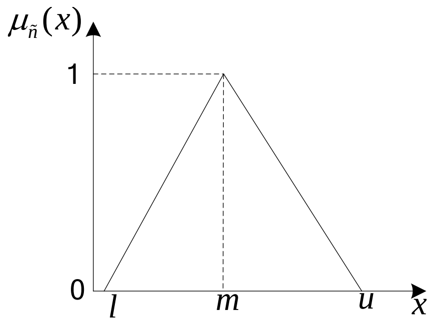

Figure 3. Triangular Fuzzy Number $\tilde{n}$

Given any two PTFNs, $\tilde{m}=(m_1,m_2,m_3)$ and $\tilde{n}=(n_1,n_2,n_3)$, some main operations can be defined as follows[5] :

$$\tilde{m}\oplus\tilde{n}=[m_1+n_1,m_2+n_2,m_3+n_3]$$
$$\tilde{m}\otimes\tilde{n}=[m_1n_1,m_2n_2,m_3n_3]$$
$$\tilde{m}^{-1}=(m_1,m_2,m_3)^{-1}=[1/m_3,1/m_2,1/m_1] \quad (2)$$

The distance between two PTFNs is computed using vertex method as follows[1] .

$$d(\tilde{m},\tilde{n})=\sqrt{\frac{1}{3}(m_1-n_1)^2+(m_2-n_2)^2+(m_3-n_3)^2} \quad (3)$$

A linguistic variable is a variable whose values are expressed in a natural language. The linguistic variable provides a way of dealing with vague situations, which are too complex to be characterized in the traditional quantitative terms[6]. In this study, the importance weight of each criterion is describled in linguistic variable, moreover, which can be expressed in PTFNs, as shown in Figure 4.

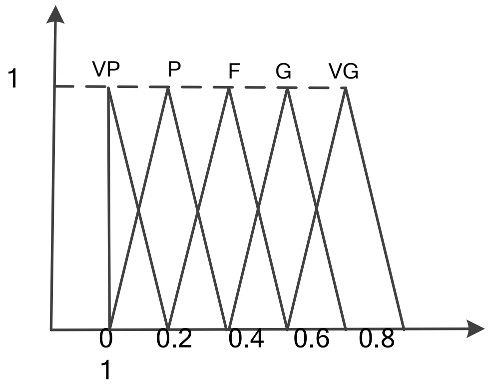

Figure 4. Linguistic Variables for Importance Weight of each Criterion

This study adopts fuzzy AHP to determine the fuzzy preference weights, and the procedure can be briefly summarized as follows:

Step 1: Construct a hierarchical model, which has three levels. From the top level to bottum level are overall goal of the MCDM problems, multiple criteria, and alternatives respectively.

Step 2: Compare the alternatives and the criteria at each level and build the evaluation matrix. The pairwise comparison starts from the middle level and finishes in the bottom level according to the influence and specified criteria in the higher level, based on the standardized scale of nine levels, details can be found in [3]. The pairwise comparison matrix evaluated by the kth expert is as:

$$\mathbf{A}_k = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & 1 \end{bmatrix}, k = 1, 2, ..., K \tag{4}$$

Step 3: Calculate and normalize the relative weights for each matrix. The relative weights can be obtained by the right eigenvector $\mathbf{w}_k$ corresponding to the largest eigenvalue $\lambda_{\max}$.

$$\mathbf{A}_k \mathbf{w}_k = \lambda_{\max} \mathbf{w}_k \tag{5}$$

However, the consistency of the pairwise comparison judgments plays a critical role on the output of the AHP. The consistency index (CI) is defined as

$$\mathrm{CI} = (\lambda_{\max} - n)/n - 1 \tag{6}$$

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \tag{7}$$

The consistency ratio (CR), computed as the ratio of CI and the random index, is used to determine whether the evaluation are sufficiently consistent. The accepted upper limit for CR is 0.1. Thus, if $\mathrm{CR}>0.1$, the evaluation process has to be modified in order to increase the consistency until $\mathrm{CR}<0.1$.

Step 4: Calculate the Synthesized weights for each criterion:

$$\mathbf{W}_{\text{final}} = [\mathbf{w}_1 \quad \mathbf{w}_2 \quad \cdots \quad \mathbf{w}_K] \mathbf{w}_{\text{expert}}^T \tag{8}$$

4.3 Fuzzy TOPSIS Methods

TOPSIS method is an important method of multi-attribute decision-making, whose basic idea is that the best alternative should have the shortest distance from the Positive Ideal Solution (PIS) and the farthest distance from the Negative Ideal Solution (NIS)[6] .

Step 1: Build a decision matrix, which can be denoted as follows:

$$\tilde{\mathbf{D}} = \begin{array}{c} \\ A_1 \\ A_2 \\ \vdots \\ A_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_n \end{array} \\ \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix} \end{array},$$

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

$$\tilde{x}_{ij} = \frac{1}{K}\left(\tilde{x}_{ij}^1 \oplus \cdots \oplus \tilde{x}_{ij}^k \oplus \cdots \oplus \tilde{x}_{ij}^K \right) \tag{9}$$

Where $\tilde{x}_{ij}^k$ is the rating of alternative A_i evaluated by *k*th expert respecting to criterion C_j.

Step 2: Normalize the decision matrix $\tilde{\mathbf{R}} = [\tilde{r}_{ij}]_{m\times n}$. The normalized value is calculated as follows:

$$\tilde{r}_{ij} = \left(l_{ij}, m_{ij}, u_{ij} \right) \tag{10}$$

Step 3: Get the weighted fuzzy normalized decision matrix, which can be denoted as $\tilde{\mathbf{V}} = [\tilde{v}_{ij}]_{m\times n}, i = 1, 2, ..., m; \; j = 1, 2, ..., n$, where $\tilde{v}_{ij} = \tilde{r}_{ij} \otimes \tilde{w}_j$.

Step 4: Identify fuzzy positive-ideal solutions (FPIS) A^{+} and fuzzy negative-ideal solutions (FNIS) A^{-} as following formula:

$$A^{+} = (\tilde{v}_1^{*},...,\tilde{v}_j^{*},...,\tilde{v}_n^{*})$$
$$A^{-} = (\tilde{v}_1^{-},...,\tilde{v}_j^{-},...,\tilde{v}_n^{-}) \quad (11)$$

Table 1. The Pairwise Comparison Matrix and Weights for Criteria by Three Experts

		C1	C2	C3	C4	C5	C6	C7	C8	Weights	CR
E1	C1	1	1/3	1/3	1/2	2	1	1/2	1/4	0.0673	0.0892
	C2	3	1	1	2	3	2	1/2	2	0.1720	
	C3	3	1	1	2	1/2	1/2	1/6	1/3	0.0928	
	C4	2	1/2	1/2	1	2	1	1/2	1/3	0.0866	
	C5	1/2	1/3	2	1/2	1	1/2	1/6	1/2	0.0595	
	C6	1	1/2	2	1	2	1	1/3	1/2	0.0894	
	C7	2	2	6	2	6	3	1	1	0.2497	
	C8	4	1/2	3	3	2	2	1	1	0.1827	
E2	C1	1	2	2	1/2	2	1/3	1/2	1/2	0.0956	0.0767
	C2	1/2	1	1	1/2	4	1/2	1/2	1/2	0.0876	
	C3	1/2	1	1	1/3	3	1/2	1/5	1/3	0.0659	
	C4	2	2	3	1	2	1/5	1/2	1/3	0.1130	
	C5	1/2	1/4	1/3	1/2	1	1/2	1/4	1/2	0.0479	
	C6	3	2	2	5	2	1	1/4	1/2	0.1620	
	C7	2	2	5	2	4	4	1	2	0.2559	
	C8	2	2	3	3	2	2	1/2	1	0.1721	
E3	C1	1	1/2	3	1/2	2	1/3	1/2	1/3	0.0790	0.0987
	C2	2	1	1	2	4	1/2	1/2	2	0.1508	
	C3	1/3	1	1	1/3	3	1/2	1/5	1/3	0.0666	
	C4	2	1/2	3	1	2	1/2	1/2	1/3	0.0961	
	C5	1/2	1/4	1/3	1/2	1	1/2	1/6	1/2	0.0449	
	C6	3	2	2	2	2	1	1/3	1/2	0.1408	
	C7	2	2	5	2	6	3	1	1/2	0.2210	
	C8	3	1/2	3	3	2	2	2	1	0.2009	

Table 2. Fuzzy Evaluation Matrix for the Alternative Contractor

	C1	C2	C3	C4
A1	(0.3500,0.4800,0.7200)	(0.4000,0.6300,1.0000)	(0.4900,0.6933,0.9000)	(0.4900,0.6400,0.8100)
A2	(0.4900,0.6400,0.8100)	(0.6400,0.8100,1.0000)	(0.5600,0.7800,1.0000)	(0.4900,0.6933,0.9000)
A3	(0.5600,0.7200,0.9000)	(0.5600,0.7500,1.0000)	(0.4900,0.7511,1.0000)	(0.5600,0.7200,0.9000)
A4	(0.4900,0.6400,0.8100)	(0.4000,0.6600,0.9000)	(0.3500,0.5778,0.9000)	(0.4900,0.6400,0.8100)
A5	(0.3500,0.4800,0.7200)	(0.5600,0.7200,0.9000)	(0.3500,0.5200,0.8000)	(0.4900,0.6400,0.8100)
	C5	**C6**	**C7**	**C8**
A1	(0.4900,0.6400,0.8100)	(0.2800,0.5600,0.8100)	(0.3200,0.6300,0.9000)	(0.3556,0.7000,1.0000)
A2	(0.5600,0.7200,0.9000)	(0.2800,0.4000,0.5400)	(0.3200,0.6300,0.9000)	(0.3556,0.7000,1.0000)

A3	(0.4900,0.6667,0.9000)	(0.4900,0.6667,0.9000)	(0.3200,0.4500,0.6000)	(0.3556,0.7000,1.0000)
A4	(0.4900,0.6667,0.9000)	(0.2800,0.4800,0.8100)	(0.3200,0.6300,0.9000)	(0.3556,0.6000,1.0000)
A5	(0.3500,0.4800,0.7200)	(0.4900,0.6933,0.9000)	(0.3200,0.5700,1.0000)	(0.6222,0.8000,1.0000)

Step 5: Compute the distance from FPIS A^{+} and FNIS A^{-} of each alternative by the vertex method.

$$d_j^{*} = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_i^{*}), \quad i = 1, 2, ..., m; \; j = 1, 2, ..., n \tag{12}$$

$$d_j^{-} = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}_i^{-}), \quad i = 1, 2, ..., m; \; j = 1, 2, ..., n \tag{13}$$

Step 6: Obtain the closeness coefficients to the ideal solution, then rank the alternatives according to cc_j in descending order.

$$cc_j = \frac{d_j^{-}}{d_j^{*} + d_j^{-}}, \; j = 1, 2, ..., n \tag{14}$$

5. Numerical Example

For this application, the decision committee was formed by three experts, and the importance weights of the three experts can be denoted by a vector $\mathbf{w}_{\text{expert}} = \{0.4, 0.3, 0.3\}$. The criteria system was determined by the committee, and the pairwise comparison matrices were fulfilled by the same team as well. The important weights of each criterion and alternatives are computed by the fuzzy AHP and fuzzy TOPSIS methods based on the steps provided above [7] .

The process of outcome-based contractor selection problem is summarized as follows:

Step 1: The hierarchical structure of outcome-based contractor selection problem is shown in Figure 2.

Table 3. The Pairwise Comparison Matrix for Criteria

	Weights Evaluated by experts			Synthesized weights
	E1	E2	E3	
C1	0.0673	0.0956	0.0790	0.0793
C2	0.1720	0.0876	0.1508	0.14032
C3	0.0928	0.0659	0.0666	0.07687
C4	0.0866	0.1130	0.0961	0.09737
C5	0.0595	0.0479	0.0449	0.05164
C6	0.0894	0.1620	0.1408	0.1266
C7	0.2497	0.2559	0.2210	0.24295
C8	0.1827	0.1721	0.2009	0.18498

Step 2: Compare the alternatives and the criteria at each level and build the evaluation matrix.

(1) The linguistic scales are transferred to the corresponding fuzzy number, and then we can obtain the pairwise comparison matrices as shown in Table 1.

(2) Calculate the entries of the synthetic pairwise comparison matrix as equation:

$$\tilde{a}_{ij} = (\tilde{a}_{ij}^{1} \otimes \tilde{a}_{ij}^{2} \otimes \tilde{a}_{ij}^{3})^{1/3} \tag{15}$$

(3) The fuzzy weights of dimensions can be calculated by Eq. (5) and (8).

Step 3: Build the fuzzy-decision matrix and take the appropriate linguistic variables from Table 5 for each alternative. The ratings of the alternatives evaluated by three experts under eight criteria are shown in Table 4.

Step 4: Normalize the fuzzy-decision matrix using Eq.(10), and get the weighted normalized fuzzy-decision matrix as shown in Table 2.

Step 5: Calculate the distances of each alternative using Eq.(12) and(13).

Step 6: then the closeness coefficients of each alternative can be obtained by Eq.(14). The results are shown in Table 6.

Based on the CC value in Table 6, the ranking of alternatives in descending order are A3, A2, A5, A4, A1. Therefore, the alternative contractor A3 is better than other alternatives.

Table 4. Ratings of the Alternatives Evaluated by Three Experts under Eight Criteria

Criteria	Alternatives	Experts		
		E1	E2	E3
C1	A1	G	P	G
	A2	F	VG	VG
	A3	F	VG	G
	A4	VG	G	G
	A5	G	G	P
C2	A1	G	G	P
	A2	VG	F	VG
	A3	G	F	P
	A4	G	VG	G
	A5	P	G	G
C3	A1	G	G	VG
	A2	F	VG	G
	A3	G	G	P
	A4	VG	G	G
	A5	G	P	VG
C4	A1	G	G	F
	A2	F	VG	G
	A3	F	G	P
	A4	VG	G	G
	A5	G	P	VG
C5	A1	F	G	VG
	A2	G	VG	G
	A3	F	P	P
	A4	VG	G	G
	A5	G	P	VG
C6	A1	G	G	F
	A2	G	VG	G
	A3	F	P	P
	A4	VG	G	G
	A5	G	P	VG
C7	A1	G	G	F
	A2	G	VG	G
	A3	F	P	P
	A4	VG	G	G
	A5	G	P	G
C8	A1	G	G	G
	A2	P	VG	F
	A3	F	P	P
	A4	VG	VG	G
	A5	G	P	G

Table 5. Linguistic Values and Corresponding Fuzzy Numbers

Linguistic variable	Triangular fuzzy number
Very poor (VP)	(0, 0, 0.2)
Poor (P)	(0, 0.2, 0.4)
Fair (F)	(0.2, 0.4, 0.6)
Good (G)	(0.4, 0.6, 0.8)
Very good (VG)	(0.6, 0.8, 1)

Table 6. Closeness Coefficients among Five Contractors

	A1	A2	A3	A4	A5
d_i^+	0.5659	0.5983	0.6016	0.5614	0.5811
d_i^-	0.6007	0.5974	0.5880	0.5959	0.6159
cc_i^+	0.4851	0.5004	0.5057	0.4850	0.4855

6. Conclusions

The outcome-based contractor selection problem has a great influence on the efficiency of the national defense system. The purpose of this study consists of two. One is to establish a rational criteria system for the outcome-based contractor selection problem, including cooperation ability, technical capacity, management capacity, financial stability, past performance, experience, reputation and resources. The other is to eastablish a fuzzy AHP and fuzzy TOPSIS model to assess different alternative contractors, which is not only considering the importance of each criterion evaluated by the decision committee through pairwise comparison, but also considering the uncertainty of human decision-making in fuzzy environment.

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