Equipment Procurement Efficiency Evaluation Based on Fuzzy Analytical Hierarchy Process and Fuzzy Comprehensive Judgment

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Abstract. When evaluating the efficiency of equipment procurement, qualitative analysis is mainly used while lack of quantitative analysis. To solve this problem, a new method based on fuzzy analytical hierarchy process (FAHP) and multi-level fuzzy analytical process is put forward. By setting up a system of procurement efficiency evaluation and using the synthesis of fuzzy math and analytical hierarchy process, we have learnt how to get the eigenvalue of comprehensive evaluation indicator, membership function and its weight and set the secondary fuzzy analytical process. It has been proved that the mode can quantitatively analyze whether the procurement efficiency of equipment budget is good or not and it has a guiding significance to improve the evaluation method of equipment purchase.

Introduction

With the development of science and technology, all kinds of equipments in national economic and military fields have become more and more systematized and high-technical, the equipments purchasing and maintaining expense has increased by a large margin, the contradiction between demand and the lack of budget has become a common problem of equipments purchasing in various countries, only by upgrading the level of management, quality and efficiency of equipments purchasing can we provide equipments of advanced level, reliable quality and reasonable price for frontlines of various fields, and make full use of the budget. Nowadays, in our country, there are still plenty of problems remain unsolved in the process of equipments purchasing, such as no well-structured system, asymmetric purchase information, unreasonable prices and so on, which urgently requires us to find a way characterized by less input , higher efficiency, better system structure, and more achievements to raise the efficiency of budget using. Therefore, we must figure out how to design a reasonable target norm to evaluate the efficiency of equipments purchasing, meanwhile, using relevant mathematics theory to analyze equipments purchasing comprehensively and scientifically, which is of great significance.

Establishing the indicator system for evaluating equipment procurement efficiency

A standard or scale is necessary to evaluate the efficiency of equipment procurement. Since there are many complex factors affecting the efficiency of equipment procurement, it is of great priority to establish a scientific and rational indicator system for evaluating the efficiency of equipment procurement. This paper, in accordance with the principle of comprehensiveness, independence, representativeness and objectivity [1-2], selects and establishes the evaluation indicators for equipment procurement:

Macro efficiency indicators. The macro efficiency indicator of equipment procurement U_1 includes four aspects as the qualified equipment rate U_{11}, qualified specification rate U_{12}, equipment quantity accuracy rate U_{13}, and customers' satisfaction rate U_{14}, among which, U_{11} refers to the percentage of qualified equipments number to total number of procured equipments;

U_{12} refers to the percentage of equipments which meet specification requirements to total number of procured equipments; U_{13} refers to whether the actual quantity of equipment procured can meet users' demand or not; U_{14} refers to the satisfaction level of equipment procurement personnel.

$$U_{11}=\frac{C_Q}{C_T}\times 100\% \qquad (1)$$

$$U_{12}=\frac{C_A}{C_T}\times 100\% \qquad (2)$$

$$U_{13}=\frac{C_T}{C_R}\times 100\% \qquad (3)$$

$$U_{14}=\frac{C_M}{C_U}\times 100\% \qquad (4)$$

$$U_1=U_{11}\times w_1+U_{12}\times w_2+U_{13}\times w_3+U_{14}\times w_4 \qquad (5)$$

In the formula,, C_Q is the number of qualified equipments procured; C_T is the total number of purchased equipments; C_A is the number of procured equipments which meet specification requirements; C_R is customer's demanded number of equipments; C_M is the number of customers who are satisfied with equipments; C_U is the total number of personnel related with using, maintaining and managing equipment; w_1, w_2, w_3, w_4 are the weight of each secondary indicator, $\sum_{i=1}^{4} w_i = 1$. In the above indicators, the bigger U_{11}、U_{12}、U_{13}、U_{14} are, the better equipment procurement efficiency is.

Economic efficiency indicators. U_2, the economic efficiency of equipment procurement, mainly includes five aspects as saved amount of equipment procurement U_{21}, saving rate of equipment procurement U_{22}, budget loss cost of equipment procurement U_{23}, surplus amount of equipment procurement U_{24}, equipment procurement price index U_{25}. U_{21} means the gap between equipment procurement budget amount and actual procurement expense in certain period of time; U_{22} means the percentage of saved amount of equipment procurement to budget amount in certain period of time; U_{23} means the army's expenditure in procuring equipment in certain period of time; U_{24} means the gap between saved amount of equipment procurement and indirect cost; U_{25} reflects the variation degree of comparable equipment procurement price in report period and base period, and it's used to compare with corresponding raw material unit price to see the benefit of equipment procurement department to production department in improving productivity, lowering down production price and saving procurement expense.

$$U_{21}=M_B-M_F \qquad (6)$$

$$U_{22}=U_{21}/M_B\times 100\% \qquad (7)$$

$$U_{23}=M_C+M_D \qquad (8)$$

$$U_{24} = \sum (M_S - M_J) \quad (9)$$

$$U_{25} = \frac{\sum (M_k \times M_m)}{\sum (M_t \times M_m)} \times 100\% \quad (10)$$

In this formula, M_B is the equipment procurement budget amount, M_F the actual equipment procurement expenditure, M_C daily office expense in equipment procurement, namely the expenditure by procurement personnel in their office work including fixed asset purchase expense, office supplies expense, M_D bidding expense of equipment procurement, namely the expense incurred by procurement operating unit in the bidding process, including announcement expense, meeting expense, notary expense and judges compensation etc, M_S the saved procurement amount of a certain type of equipment, M_J the indirect cost of procuring a certain type of equipment, M_k the procurement comparable price in report period, M_m the quantity of procured equipment in report period, M_t the procurement comparable price in base period.

Equipment utilization efficiency indicators. Equipment utilization efficiency indicators evaluate the efficiency of equipment procurement from aspects of equipment performance, reliability and effectiveness etc. Equipment efficiency indicator U_3 mainly includes four aspects as equipment effectiveness rate U_{31}, equipment update rate U_{32}, equipment advanced degree U_{33}, equipment usage reliability U_{34}, among which, U_{31} is the difference between the technical indicators of procured equipment and that of the users' requests; U_{32} is the percentage of procured equipment quantity to user's total equipment quantity; U_{33} means the advanced degree of procured equipments' performance, features, creativity and functions etc; U_{34} is the probability of procured equipment failure in usage and maintenance.

Equipment procurement management efficiency indicators. Equipment procurement management efficiency indicators evaluate equipment procurement efficiency combining the management rules, management standardization, management efficiency, procurement personnel's professional skills, equipment procurement department's development potential and external response from the perspectives of organization building, personnel quality and other factors which restrict procurement efficiency. Procurement management efficiency indicator U_4 includes management rule establishment U_{41}, management efficiency U_{43}, procurement personnel's professional skills U_{44}, equipment procurement department's development potential U_{45}, and procurement personnel's ability to guard against economic crime U_{46}.

Evaluation indicators' weight calculation based on fuzzy analytical hierarchy process

In traditional analytical hierarchy process, the weight calculation of evaluation indicators is subject to judgmental ambiguity, individual preference and preference. To make more rational decision, this paper, based on analytical hierarchy process, comes up with the method to decide the indicator weight of risk evaluation model on equipment budget guarantee. And the steps are as follows [3-4]:

(1) Build triangular fuzzy complementary judgment matrix

The role of judgment matrix is to compare the relative importance of factors in the same level under the conditions of the upper level indictors. Assume any factor with subordinate factor has a judgment matrix $\tilde{A}=(\tilde{a}_{ij})_{n\times n}$. $\tilde{a}_{ij}=(l_{ij},m_{ij},u_{ij})$ means the ratio of importance between i factor and j factor, and $u_{ij}\geq m_{ij}\geq l_{ij}$, $l_{ij}+u_{ji}=m_{ij}+m_{ji}=l_{ji}+u_{ij}=1$, then $\tilde{A}$ is the triangular complementary judgment matrix. The judgment matrix is obtained by Delphi method, namely if there are t judges, then every factor of the judgment matrix can be valued through:

$$\tilde{a}_{ij}=(\lambda_1\otimes\tilde{a}_{ij}^{\ 1})\oplus(\lambda_2\otimes\tilde{a}_{ij}^{\ 2})\oplus\cdots\oplus(\lambda_t\otimes\tilde{a}_{ij}^{\ t}) \tag{12}$$

In this formula, λ_k refers to k expert's opinion weight, and $\sum_{k=1}^{t}\lambda_k=1$. Especially, when the opinions of t experts are equally important, then the above formula becomes:

$$\tilde{a}_{ij}=\frac{1}{t}\otimes(\tilde{a}_{ij}^{\ 1}\oplus\tilde{a}_{ij}^{\ 2}\oplus\cdots\oplus\tilde{a}_{ij}^{\ t})=(\frac{1}{t}\sum_{k=1}^{t}a_{ijl}^{\ k},\frac{1}{t}\sum_{k=1}^{t}a_{ijm}^{\ k},\frac{1}{t}\sum_{k=1}^{t}a_{iju}^{\ k}) \tag{13}$$

In this formula, $\tilde{a}_{ij}^{\ k}$ refers to j factor in line i of the judgment matrix provided by k expert.

(2) Fuzzy weight calculation of single-level factor

To get the weight of all factors relative to the upper level factors, the weight of single level factors must be obtained first. There are n factors under a certain upper level factor, and this paper acquires the triangular fuzzy weight vector of i factor relative to the upper level factor by the following formula:

$$\tilde{w}_i=\frac{\sum_{j=1}^{n}\tilde{a}_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}\tilde{a}_{ij}}=\frac{\left(\sum_{j=1}^{n}l_{ij},\sum_{j=1}^{n}m_{ij},\sum_{j=1}^{n}\mu_{ij}\right)}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n}l_{ij},\sum_{i=1}^{n}\sum_{j=1}^{n}m_{ij},\sum_{i=1}^{n}\sum_{j=1}^{n}\mu_{ij}\right)}=\left(\frac{\sum_{j=1}^{n}l_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}l_{ij}},\frac{\sum_{j=1}^{n}m_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}m_{ij}},\frac{\sum_{j=1}^{n}\mu_{ij}}{\sum_{i=1}^{n}\sum_{j=1}^{n}\mu_{ij}}\right),i=1,2,\cdots n \tag{14}$$

(3) Build the possibility matrix

The obtained triangular fuzzy weight is not the certain value of the wanted indicator factor, so this paper deals with $\tilde{w}_i$, $(i\in N)$ by the method of possibility, namely make pair wise comparison of the triangular fuzzy number $\tilde{w}_i$. Assume $\tilde{a}=(a_l,a_m,a_u)$, $\tilde{b}=(b_l,b_m,b_u)$, then the possibility of $\tilde{a}\geq\tilde{b}$ is:

$$P(\tilde{a}\geq\tilde{b})=\lambda\max\left\{1-\max\left\{\frac{b_m-a_l}{a_m-a_l+b_m-b_l},0\right\},0\right\}+(1-\lambda)\max\left\{1-\max\left\{\frac{b_u-a_m}{a_u-a_m+b_u-b_m},0\right\},0\right\} \tag{15}$$

In this formula, λ is the risk coefficient, and $\lambda\in[0,1]$. When $\lambda>0.5$, then the decision-maker is risk-seeking; $\lambda=0$, risk-neutral; $\lambda<0.5$, risk-averse. This paper takes $\lambda=0.5$.

Calculate the ordering vector of possibility matrix

(4) Build possibility matrix $P=(p_{ij})_{n\times n}$ according to $p_{ij}(w_i\geq w_j)$, $(i,j\in N)$, convert the possibility matrix into fuzzy consistent matrix. Assume $r_i=\sum_{k=1}^{n}p_{ik}$, $i=1,2,\cdots,n$, then $r_{ij}=\frac{r_i-r_j}{2(n-1)}+0.5$, and obtain the fuzzy consistent matrix $R=\left(r_{ij}\right)_{n\times n}$. The ordering vector $V_i=\frac{1}{n}\left(\sum_{j=1}^{n}r_{ij}+1-\frac{n}{2}\right)$ can be obtained using ordering formula, and each value of Tetris ordering vector is the weight of each factor.

Equipment procurement efficiency evaluation model based on fuzzy comprehensive judgment

The purpose of equipment procurement efficiency evaluation is to know and reveal the usage of equipment procurement budget, find factors that affect the guarantee on equipment procurement budget, analyze, study and demonstrate resource consumption, budget expenditure, input ad output, choose the best option so as to achieve the biggest result using least budget. To evaluate equipment procurement efficiency rationally, this paper proposes to build two-level fuzzy comprehensive judgment model as follows [5-8]:

Step 1: Build factor sets $U=\{(U_{11},U_{12},...,U_{14}),(U_{21},U_{22}...,U_{25}),(U_{31},U_{32},...,U_{34}),(U_{41},U_{42},...,U_{46})\}$, and classify the factor sets into several groups, namely, $U=\{U_1,U_2,...,U_4\}$, so that $U=\bigcup U_i$, $U_i \cap U_j=\varnothing (i\neq j)$, $i,j=1,2,...,4$, then $U=\{U_1,U_2,...,U_4\}$ is the first level factor sets.

Step 2: Build weight sets

① Set $A=(\lambda_1,\lambda_2,...,\lambda_4)$ as the weight vector of the first level factor sets $U=\{U_1,U_2,...,U_4\}$;

② Set $A_i=(\lambda_{i1},\lambda_{i2},...,\lambda_{in_i})$ as the weight vector of the first level factor sets $U_i=\{U_{i1},U_{i2},...,U_{in_i}\}$. $i=1,2,...,4$, refers to the number of factors included by each first level factor;

Step 3: First level fuzzy judgment. Given judgment sets $V=\{v_1,v_2,...,v_5\}$, first judge the single factor of n_i in the second level factor sets $U_i=\{U_{i1},U_{i2},...,U_{in_i}\}$ and obtain the single factor judgment matrix:

$$R_i=\begin{bmatrix} r_{11}^{(i)} & r_{12}^{(i)} & \cdots & r_{15}^{(i)} \\ r_{21}^{(i)} & r_{22}^{(i)} & \cdots & r_{25}^{(i)} \\ \vdots & \vdots & \vdots & \vdots \\ r_{n_i1}^{(i)} & r_{n_i2}^{(i)} & \cdots & r_{n_i5}^{(i)} \end{bmatrix} \quad (16)$$

Adopting fuzzy judgment model to acquire the fuzzy comprehensive judgment of type i factors:

$$B_i=A_iR_i=(b_{i1},b_{i2},...,b_{i5}) \quad (17)$$

Step 4:Second level comprehensive judgment. Comprehensively judge on the first level factor sets $U=\{U_1,U_2,...,U_4\}$, and the judgment matrix is the first level fuzzy comprehensive judgment matrix:

$$R=\begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_4 \end{bmatrix}=\begin{bmatrix} A_1*R_1 \\ A_2*R_2 \\ \vdots \\ A_4*R_4 \end{bmatrix} \quad (18)$$

Adopting the fuzzy judgment model, the second level fuzzy comprehensive judgment is:

$$B=A\bullet R=(b_1,b_2,..,b_5) \quad (19)$$

The comprehensive judgment result B obtained from the above formula is a vector, which describes the comprehensive efficiency of the evaluated subjects. Following the maximum principle, the result B can be used to decide the efficiency grade of the evaluated subjects.

Case analysis of equipment procurement efficiency evaluation

Take a certain department's equipment procurement situation as example, this paper, considering the ambiguity of qualitative indicators, first grades equipment procurement efficiency into five grades using the grading system, as shown in table 1.

Table 1 Grades of equipment procurement efficiency

Grade	Level Ⅰ	Level Ⅱ	Level Ⅲ	Level Ⅳ	Level Ⅴ
Description	Excellent	Good	Fine	Normal	Poor
Score range	［0.85，1.00］	［0.65，0.85）	［0.45，0.65）	［0.25，0.45）	［0.00，0.25）

Then decide the degree of membership of each evaluating indicator and further classify indicators that can be directly quantified. To quantify qualitative evaluation indicators, first design the score table, and evaluate the qualitative indicators in the second level indicator sets by the five grades according to 49 experts' opinion. And the membership degree of their upper level factors can be calculated through their evaluation result and corresponding weight. Take management rule building for example, 18 out of 49 experts think it's "Excellent", 20 "Good", 10 "Fine", 1 "Normal", 0 "Poor". Then the membership degree of U_{41} in "Excellent"grade is 18/49; "Good"20/49; "Fine"10/49; "Normal"1/49; "Poor"0; Then the evaluation of U_{41} is $V_{41}=(18/49, 20/49, 10/49, 1/49, 0)$.

Based on this quantification, before calculating the weight sets of each level evaluation indicators, experts are needed to make pair wise comparison among each evaluation factor by degree of importance and show by triangular fuzzy number. Suppose $\tilde{a}_{ij}=\left(l_{ij}, m_{ij}, u_{ij}\right)$ is a triangular fuzzy number, which refers to the membership degree of "… is more important than …" between factor x_i and x_j under certain restrictions. l_{ij}, m_{ij}, u_{ij} refers to experts' pessimistic, most likely and optimistic estimation of factor x_i and x_j relative to the upper level factors. Table 2 provides the scale of triangular fuzzy number.

Table 2 Scale standards of triangular fuzzy number

Scale	Meaning
0.9	One risk factor is extremely important relative to the other.
0.8	One risk factor is highly important relative to the other.
0.7	One risk factor is obviously important relative to the other.
0.6	One risk factor is slightly important relative to the other.
0.5	One risk factor is equally important relative to the other.
0.1-0.4	Reverse comparison. If risk factor x_i to x_j equals a_{ij}, x_i to x_j obtains the judgment of $a_{ij}=1-a_{ji}$

This paper adopts Delphi method in obtaining experts' judgment matrix on each level of indicators as follows. This is the fuzzy complementary judgment matrix of the "equipment usage efficiency indicator U_3", as shown in table 3.

Table 3 Fuzzy complementary judgment matrix of U_3

U3	Equipment effectiveness	Equipment update rate	Equipment advanced degree	Equipment usage reliability
Equipment effectiveness	(0.5,0.5,0.5)	(0.4,0.5,0.6)	(0.4,0.6,0.7)	(0.4,0.5,0.7)
Equipment update rate	(0.4,0.5,0.6)	(0.5,0.5,0.5)	(0.4,0.6,0.7)	(0.5,0.6,0.8)
Equipment advanced degree	(0.3,0.4,0.6)	(0.3,0.4,0.6)	(0.5,0.5,0.5)	(0.4,0.5,0.6)
Equipment usage reliability	(0.3,0.5,0.6)	(0.2,0.4,0.5)	(0.4,0.5,0.6)	(0.5,0.5,0.5)

According to the obtained fuzzy complementary judgment matrix of each indicator using the above-mentioned methods, the weight value of each subordinate level of indicators relative to upper level indicators can be obtained by fuzzy analytical hierarchy process, namely the weight vector of first level evaluation indictors $U_i(i=1,2,\cdots,4)$ is $A=(\lambda_1,\lambda_2,\cdots,\lambda_4)$=(0.1277,0.1264,0.1177,0.0939). The weight vector of second level evaluation indictors under corresponding first level indicator is $A_i=(\lambda_{i1},\lambda_{i2},\cdots,\lambda_{in_i})$. And the weight of each level indicators can be obtained by sorting out the above-mentioned weights. Comprehensive judgment matrix R of risk evaluation ability U can be calculated using the comprehensive judgment result B_i of first level evaluation indicator Ui. Then B, the comprehensive evaluation result of U , can be obtained.

$$B = A \bullet R = [\lambda_1, \lambda_2, \cdots, \lambda_4] \bullet \begin{bmatrix} B_1 \\ B_2 \\ \vdots \\ B_5 \end{bmatrix} = [0.2905 \quad 0.3141 \quad 0.2643 \quad 0.0935 \quad 0.0376] \tag{20}$$

Analyzing B_i by the maximum membership principle, the grading distribution of this department's equipment procurement efficiency in the five grades from Excellent to Poor is 29.5%、31.41%、26.43%、9.35%、3.76% respectively. Therefore, the percentage of "Good" is the highest, and this department's equipment procurement efficiency can be evaluated as "Good".

Conclusion

(1) This paper builds the comprehensive indicator system including four first level indicators and 19 second level indicators to quantitatively evaluate equipment procurement efficiency, and raises the method to quantify the qualitative indicator parameters of equipment procurement efficiency, which provides the basis for evaluating equipment procurement efficiency scientifically.
(2) This paper puts forward the method to decide the weight of equipment procurement efficiency indicators based on fuzzy analytical hierarchy process, which overcomes the disadvantage of subjective judgment in traditional analytical hierarchy process. This method builds the possibility matrix by setting up triangular fuzzy number complementary judgment matrix, uses ordering method to convert the possibility matrix into fuzzy consistent matrix so that the weight of the evaluation model indicators can be more rationally decided.
(3) This paper puts forward the two-level fuzzy comprehensive evaluation model of equipment procurement efficiency, identifies the weight of each level factor by fuzzy analytical hierarchy process, identifies subordinate functions using Delphi method, classifies the five grades of equipment procurement efficiency, and provides the equipment procurement efficiency evaluation process based on fuzzy analytical hierarchy process and multi-level fuzzy comprehensive evaluation model.
(4) This paper takes a certain department as example, and comprehensively evaluates the department's procurement work using the two-level fuzzy comprehensive evaluation model. The evaluation result shows that this model can quantitatively analyze equipment procurement efficiency, which can guide and improve the two-level fuzzy comprehensive evaluation ability.

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