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Using a Fuzzy AHP-VIKOR and BSC Approach for Evaluating Aircraft Maintenance Unit Performance

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Abstract

Today performance evaluation is known as an inevitable part of management knowledge; in such a way that it can help an organization to consume sources and facilities in an optimum way and also achieve its goals and strategies. In this paper for evaluating the performance of aircraft maintenance unit in Iran, Balanced Scorecard (BSC), a strategic management method for performance measurement using a set of financial and non-financial performance metrics, and Fuzzy Multiple Criteria Decision Making (FMCDM) has been used. 26 criteria for performance evaluation in four BSC perspectives by help of maintenance unit's experts have been specified. The criteria's weights via Fuzzy Analytic Hierarchy Process (FAHP) method by using Fuzzy Preference Programming (FPP) approach determined and finally fuzzy VIKOR method has been used to measure the performance of three aircraft maintenance units. Results of research shows that FAHP-FVKIOR evaluation method by BSC can be a useful tool for optimum measuring of performance.

Keywords: Balanced Scorecard (BSC); Fuzzy analytic hierarchy process (FAHP); FVIKOR; FPP.

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Introduction

Performance evaluation is a holistic method for measurement of efficiency of a company for achieving its goals (Wu and Hung, 2008). In this regard there are some performance measurement tools that facilitates this operation and puts organization by management. Balanced scorecard is one of the known and popular of these methods between many companies because it has the ability of considering financial and non-financial aspects of the organization for performance evaluation (Wu et al., 2009). Performance evaluation was used in several studies for ranking the units according to various performance measurement tools. For example Xiaoli and Guangbin (2008) by using BSC-AHP-FCA methods evaluated the performance of construction companies. Wu et al. (2009) Applied BSC and fuzzy MCDM approach for evaluation performance of three banks. Xia and Wang (2009) evaluated the performance of a software company by utilizing fuzzy AHP and BSC method based on knowledge management. Yuksel and Dagdeviren (2010) by using analytic network process (ANP) and Balanced Scorecard tried to determine the performance of a production company. As can be seen, in these studies for obtaining the optimal solution from a set of alternatives, performance evaluation is considered as a MCDM problem. Aircraft maintenance that includes of overhaul, repair, inspection, is the most important part of Air fleet that guarantees Passengers' health. Because direct role of aircraft maintenance unit in preventing plane crashes, so managers shall examine the performance of maintenance unit continously to ensure the aircrafts function. So selecting an optimum strategy for aircraft maintenance unit is very importance. In this paper for the first time, the FAHP-VIKOR, FPP and BSC approach has been used for evaluating performance. First four BSC perspectives in this unit have been considered and then by AHP method based on FPP approach, the priority of criteria and sub-criteria were identified. After that by using VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) approach, performance of three maintenance unit: P, S and U has been assessed. In this paper also fuzzy logic has been used for uncertainty.

Literature review

Balanced Scorecard

Balanced scorecard is a tool for measurement of performance that by considering financial and non-financial aspects tries to determine the strategies and perspectives of the organization and then evaluates the performance of the organization in four perspectives: customer, financial, internal business process and learning and growth (Kaplan and Norton, 1992, 1996).

Analytic Hierarchy Process

AHP is a multiple criteria decision making method which helps the determiner to evaluate the weights of criteria and sub-criteria by changing the problem to a hierarchy (Saaty, 1990).

VIKOR Method

VIKOR technique is one of the most widely used methods of multiple criteria decision making solving which could prioritize the available choices according to the intended criteria. For using this technique, at first, the best and the worst values of criteria according to below equations shall be evaluated (Pourebrahim et al., 2014).

$$f_j^* = \text{Max } f_{ij} \qquad , i = 1,2, \dots , m \tag{1}$$

$$f_j^- = \text{Min } f_{ij} \qquad , j = 1,2, \dots , n \tag{2}$$

Then, values of S_i and R_i shall be calculated according to below equations:

$$S_i = \sum_{i=1}^{n} w_i \frac{(f_i^* - f_{ij})}{(f_i^* - f_i^-)} \tag{3}$$

$$R_i = \max \left[w_i \frac{(f_i^* - f_{ij})}{(f_i^* - f_i^-)} \right] \tag{4}$$

Finally, the equation (5) for calculating Q_i value shall be used:

$$Q_i = v \frac{(S_j - S^*)}{(S^- - S^*)} + (1 - v) \frac{(R_j - R^*)}{(R^- - R^*)} \tag{5}$$

Fuzzy Theory

Fuzzy set theory has been introduced in 1965 by Zadeh. This theory is used in order to deal with ambiguity existing in problems (Zadeh, 1965). Fuzzy numbers show by a fuzzy subset of real numbers that describe the accretion of the plan of a confidence interval. The triangular fuzzy number (TFN), $\tilde{A} = (l, m, u)$, is shown in Figure 1, is defined by Zimmermann (1991) as following (Wu et al., 2009):

$$\mu_{\tilde{A}}(x) = \begin{cases} (x - l)/(m - l) & if\ l \le x \le m, \\ (u - x)/(u - m) & if\ m \le x \le u, \\ 0 & otherwise. \end{cases} \tag{6}$$

The definition of TFN of Zadeh's Viewpoint tells, for two positive TFN, $\tilde{A}_1 = (l_1, m_1, u_1)$, $\tilde{A}_2 = (l_2, m_2, u_2)$, and a positive real number r, some algebraic operations of fuzzy numbers $\tilde{A}_1$ and $\tilde{A}_2$ can be expressed as follows:

(If sum $\oplus$, fuzzy subtraction $\ominus$, multiplication $\otimes$, Division $\oslash$ of two TFNs.)

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2, m_1 + m_2, u_1 + u_2). \tag{7}$$

$$\tilde{A}_1 \ominus \tilde{A}_2 = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \quad \text{for} \quad l_i > 0, \quad l_i > 0, \quad u_i > 0 \tag{8}$$

$$\tilde{A}_1 \otimes \tilde{A}_2 = (l_1 l_2, m_1 m_2, u_1 u_2). \tag{9}$$

$$r \otimes \tilde{A}_1 = (r l_1, r m_1, r u_1) \quad \text{for} \quad r > 0 \quad \text{and} \quad l_i > 0, \quad l_i > 0, \quad u_i > 0 \tag{10}$$

$$\tilde{A}_1 \oslash \tilde{A}_2 = (l_1/u_2, m_1/m_2, u_1/l_2) \tag{11}$$

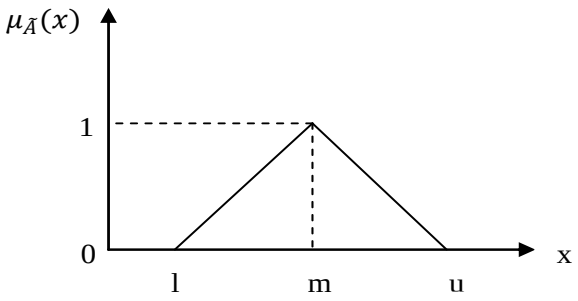

Figure 1 A positive triangular fuzzy number

Fuzzy Preference Programming

Fuzzy preference programming is based on the non-linear programming for calculating the vector weight of comparison matrix. In this preference the difficulties of other methods has been solved (Mikhailov, 2000, 2003). If fuzzy prioritisation problem has n elements, for transforming a fuzzy pairwise comparison matrix to the crisp priority vector $w = (w_1, w_2, \ldots, w_n)^T$, Mikhailov offered the following method. A comparison matrix is constructed by $m \leq n(n-1)/2$ pairwise comparisons expressed with linguistic variables. For triangular fuzzy numbers $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ results in the set $F = \{\tilde{a}_{ij} | i = 1,2,\ldots, n-1; j = 2,3,\ldots n, j > i\}$. For calculating the weights, we represent as follows:

$$l_{ij} \lessapprox \frac{w_i}{w_j} \lessapprox u_{ij} \tag{12}$$

The following membership function shows the w_i/w_j ratios linearly.

$$\mu_{ij}\left(\frac{w_i}{w_j}\right) = \begin{cases} \dfrac{\left(\frac{w_i}{w_j} - l_{ij}\right)}{m_{ij} - l_{ij}}, & \dfrac{w_i}{w_j} \leq m_{ij} \\ \dfrac{\left(u_{ij} - \frac{w_i}{w_j}\right)}{u_{ij} - m_{ij}}, & \dfrac{w_i}{w_j} \geq m_{ij} \end{cases} \tag{13}$$

The final Mikhailov method's model is as follows:

$$\text{Maximise } \lambda$$
$$\text{s.t:}$$
$$(m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \leq \cdot$$
$$(u_{ij} - m_{ij})\lambda w_j + w_i - u_{ij} w_j \leq \cdot$$
$$\sum_{k=1}^{n} w_k = 1$$
$$w_k > 0, k = 1, 2, \dots, n\,; i = 1, 2, \dots, n-1\,; j = 2, 3, \dots, n, j > i \qquad (14)$$

In this paper, Lingo 11 software has been used for obtaining optimal solution (λ^*, w^*). Positive values of λ index Indicates the relative compatibility and negative values of λ Indicates the fuzzy judgment inconsistent (Tavana et al., 2013).

Proposed Model

The analytical structure of this Study is shown in Figure 2. First four BSC perspectives have been determined. Then criteria and sub-criteria's weights were calculated by FAHP approach and FPP. After that by using calculated weights in MCDM analytical tool of VIKOR in a fuzzy environment, the aircraft maintenance units were ranked based on their performance.

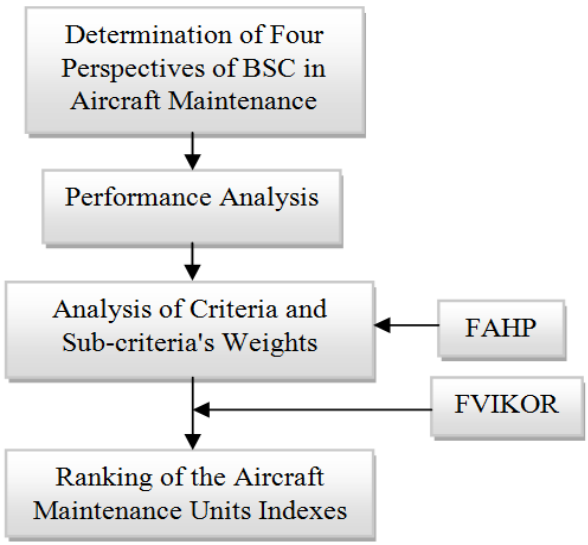

Figure 2 the process of performed research

With guidance of aircraft maintenance unit experts, four BSC perspectives as hierarchy was determined in table 1.

Table 1 Performance evaluation hierarchy of aircraft maintenance department

Goal	Perspectives	Performance indicators
Performance evaluation of aircraft maintenance department	Financial (F)	Strengthen financing (F1)
		Attracting maximum customers' funds (F2)
		Optimal utilization of assets (F3)
		Fiscal discipline (F4)
		Reducing the costs (F5)
		Developing of income opportunities (F6)
	Customer (C)	Competitiveness and enhancement the customer satisfaction (C1)
		Improving advertising and Customer Relationship (C2)
		Variety of Services (C3)
		Optimizing the cost of services (C4)
		On time Delivery (C5)
		Improving the quality and after-sales service (C6)
	Internal business process (P)	Strategic alliances with domestic and foreign companies and development Marketing capabilities and export (P1)
		Support and capacity building of infrastructure and equipment fleet and improving the projects management (P2)
		Increasing the Reliability (P3)
		Stable and efficient supply of Inventory and strengthening the logistics (P4)
		Development of Localizing Manufacture (P5)
		Promoting research and development activities (P6)
		Improvement and automation of systems and processes (P7)
		Development of upgrading and increasing the useful life (P8)
	Learning and growth (L)	Establishment and development of modern management systems (L1)
		Development of excellence, Improvement and productivity of organization (L2)
		Infrastructures development in science and technology (L3)
		Development of integrated information and communication infrastructures (L4)
		Development and empowerment of employees (L5)
		Improvement of employee satisfaction and motivation (L6)

Then via pairwise AHP questionnaires comparisons by experts of this unit using the linguistic comparison table 2, criteria and sub-criteria weights determined. Results are shown in tables 3,4,5,6,7.

Table 2 Corresponding linguistic terms for evaluation of criteria (Tavana et al., 2013).

Relative importance	Fuzzy representation
Equally important (EI)	(1,1,1)
Slightly more important (SMI)	(1/2,1,3/2)
Moderately more important (MMI)	(1,3/2,2)
Greatly more important (GMI)	(3/2,2,5/2)
Extremely more important (EMI)	(2,5/2,3)
Absolutely more important (AMI)	(5/2,3,7/2)

Table 3 Local weights and pairwise comparison matrix of BSC perspectives.

	Financial (F)	Customer (C)	Internal business process (P)	Learning and growth (L)	Weights
F	(1,1,1)	(0.921,1.369,1.778)	(0.643,1,1.919)	(0.834,1.369,1.884)	0.305
C	(0.563,0.732,1.087)	(1,1,1)	(0.642,0.808,1.151)	(0.505,0.720,1.105)	0.204
P	(0.521,1,1.563)	(0.869,1.240,1.560)	(1,1,1)	(0.549,0.763,1.271)	0.255
L	(0.532,0.732,1.200)	(0.906,1.392,1.982)	(0.787,1.314,1.825)	(1,1,1)	0.236

$\lambda = 0.680$

Table 4 Local weights and pairwise comparison matrix of financial indicator.

	F1	F2	F3	F4	F5	F6	Weights
F1	(1,1,1)	(0.552,1,1.416)	(0.877,0.906,0.944)	(0.67,1,2)	(0.521,0.709,1.104)	(0.61,1.123,1.629)	0.156
F2	(0.709,1,1.811)	(1,1,1)	(0.591,0.842,1.486)	(0.67,1,2)	(0.445,0.576,0.829)	(0.67,1,2)	0.149
F3	(1.060,1.104,1.14)	(0.673,1.19,1.697)	(1,1,1)	(0.709,1,1.811)	(0.555,0.775,1.325)	(0.743,1,1.19)	0.169
F4	(0.5,1,1.5)	(0.5,1,1.5)	(0.552,1,1.416)	(1,1,1)	(0.471,0.622,0.906)	(0.5,1,1.5)	0.135
F5	(0.906,1.416,1.919)	(1.21,1.739,2.251)	(0.756,1.292,1.809)	(1.104,1.614,2.119)	(1,1,1)	(0.5,1,1.5)	0.215
F6	(0.616,0.892,1.641)	(0.5,1,1.5)	(0.842,1,1.346)	(0.67,1,2)	(0.67,1,2)	(1,1,1)	0.175

$\lambda = 0.543$

Table 5 Local weights and pairwise comparison matrix of customer indicator

	C1	C2	C3	C4	C5	C6	Weights
C1	(1,1,1)	(0.713,1.24,1.752)	(0.67,1,2)	(0.5,0.67,1)	(0.5,1,1.5)	(1.5,2,2.5)	0.188
C2	(0.572,0.808,1.403)	(1,1,1)	(0.673,1,1.261)	(0.521,0.709,1.104)	(0.521,0.709,1.104)	(0.67,1,2)	0.162
C3	(0.5,1,1.5)	(0.795,1,1.486)	(1,1,1)	(0.469,0.616,0.892)	(0.643,0.944,1.811)	(0.616,0.892,1.641)	0.169
C4	(1,1.5,2)	(0.906,1.416,1.919)	(1.123,1.629,2.132)	(1,1,1)	(0.82,1.336,1.842)	(0.67,1,2)	0.204
C5	(0.67,1,2)	(0.906,1.416,1.919)	(0.552,1.06,1.563)	(0.544,0.751,1.219)	(1,1,1)	(0.5,1,1.5)	0.160
C6	(0.4,0.5,0.67)	(0.5,1,1.5)	(0.61,1.123,1.629)	(0.5,1,1.5)	(0.67,1,2)	(1,1,1)	0.116

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$\lambda = 0.240$

Table 6 Local weights and pairwise comparison matrix of internal business process indicator.

	P1	P2	P3	P4	P5	P6	P7	P8	Weights
P1	(1,1,1)	(0.552,1.06,1.563)	(0.751,1,1.641)	(0.5,1,1.5)	(0.67,1,2)	(0.673,1,1.261)	(0.552,1,1.416)	(0.82,1.06,1.24)	0.133
P2	(0.643,0.944,1.811)	(1,1,1)	(0.67,1,2)	(0.544,0.751,1.219)	(0.591,1,1.768)	(0.521,0.709,1.104)	(0.5,0.67,1)	(0.616,1,1.842)	0.107
P3	(0.61,1,1.336)	(0.5,1,1.5)	(1,1,1)	(1,1,1)	(0.5,1,1.5)	(0.732,1,1.369)	(0.552,1.06,1.563)	(0.552,1,1.416)	0.121
P4	(0.67,1,2)	(0.82,1.336,1.842)	(1,1,1)	(1,1,1)	(0.643,1,1.919)	(0.67,1,2)	(0.6,1.06,1.697)	(0.944,1,1.104)	0.121
P5	(05,1,1.5)	(0.567,1,1.697)	(0.67,1,2)	(0.521,1,1.563)	(1,1,1)	(0.61,1.06,1.475)	(0.61,1,1.336)	(0.67,1,2)	0.125
P6	(0.795,1,1.486)	(0.906,1.416,1.919)	(0.732,1,1.369)	(0.5,1,1.5)	(0.68,0.944,1.641)	(1,1,1)	(0.673,1.06,1.392)	(0.68,1,1.739)	0.134
P7	(0.709,1,1.811)	(1,1.5,2)	(0.643,0.944,1.811)	(0.591,0.944,1.669)	(0.751,1,1.641)	(0.72,0.944,1.486)	(1,1,1)	(0.646,1.17,1.681)	0.135
P8	(0.808,0.944,1.219)	(0.544,1,1.629)	(0.709,1,1.811)	(0.906,1,1.06)	(0.5,1,1.5)	(0.576,1,1.475)	(0.597,0.855,1.549)	(1,1,1)	0.124

$\lambda = 0.641$

Table 7 Local weights and pairwise comparison matrix of learning and growth indicator.

	L1	L2	L3	L4	L5	L6	Weights
L1	(1,1,1)	(0.5,1,1.5)	(0.622,0.906,1.711)	(0.5.0.67,1)	(0.5,1,1.5)	(1,1,1)	0.159
L2	(0.67,1,2)	(1,1,1)	(0.622,0.906,1.711)	(0.521,0709,1.104)	(0.616,0.892,1.641)	(0.67,1,2)	0.152
L3	(0.585,1.104,1.614)	(0.585,1.104,1.614)	(1,1,1)	(1,1.5,2)	(0.682,1.219,1.736)	(0.5,1,1.5)	0.211
L4	(1,1.5,2)	(0.906,1.416,1.919)	(0.5,0.67,1)	(1,1,1)	(0.743,1.19,1.601)	(0.743,1.261,1.768)	0.180
L5	(0.67,1,2)	(0.61,1.123,1.629)	(0.578,0.82,1.463)	(0.626,0.842,1.346)	(1,1,1)	(0.61,1.123,1.629)	0.138
L6	(1,1,1)	(05,1,1.5)	(0.67,1,2)	(0567,0.795,1.346)	(0.616,0.892,1.641)	(1,1,1)	0.159

$\lambda = 0.348$

Table 8 shows the final sub-criteria weight which has been obtained by multiplying criteria weights in relative sub-criteria weights.

Table 8 Overall weights and ranking of BSC performance evaluation criteria by FAHP.

BSC perspectives	Local weights	Overall weights	Rank
Financial (F)	0.305		1
F1	0.156	0.0476	5
F2	0.149	0.0455	7
F3	0.169	0.0516	4
F4	0.135	0.0413	9
F5	0.215	0.0658	1
F6	0.175	0.0536	3
Customer (C)	0.204		4
C1	0.188	0.0383	12
C2	0.162	0.0329	15
C3	0.169	0.0345	14
C4	0.204	0.0416	8
C5	0.160	0.0326	16
C6	0.116	0.0237	24
Internal business process (IBP)	0.236		3
P1	0.133	0.0313	19
P2	0.107	0.0252	23
P3	0.121	0.0286	22
P4	0.121	0.0286	22
P5	0.125	0.0295	20
P6	0.134	0.0316	18
P7	0.135	0.0320	17
P8	0.124	0.0292	21
Learning and growth (LG)	0.255		2
L1	0.159	0.0406	10
L2	0.152	0.0388	11
L3	0.211	0.0538	2
L4	0.180	0.0459	6
L5	0.138	0.0353	13
L6	0.159	0.0406	10

As it can be seen among the BSC main criteria in aircraft maintenance unit, financial criteria (F) (0.305) and also among sub-criteria, reducing the costs criteria (F5) (0.0658) have more priority than others. So this unit shall focus more on financial criteria.

For comparison of three aircraft maintenance units (P unit, L unit and U unit) fuzzy VIKOR approach has been used. For this purpose, aircraft maintenance unit experts through

linguistic variables of table 9, tried to compare these three units based on sub-criteria. By using following equation, fuzzy numbers were converted to definitive numbers (Pourebrahim et al., 2014):

$$R(A) = \frac{l + 2m + u}{4} \quad (15)$$

Table 9 Corresponding linguistic terms for evaluation of alternatives (Pourebrahim et al., 2014).

Linguistic terms	Fuzzy score
Very poor (VP)	(0,0,1)
Poor (P)	(0,1,3)
Medium poor(MP)	(1,3,5)
Fair (F)	(3,5,7)
Medium good(MG)	(5,7,9)
Good(G)	(7,9,10)
Very good(VG)	(9,10,10)

Table 10, shows the obtained results from comparisons of questionnaire by using VIKOR method. First, the best and the worst values of sub-criteria were determined and then via obtained weights from FAHP method, S_i, R_i, Q_i values has been calculated.

Table 10 Evaluation matrix for alternatives.

	F1	F2	F3	F4	F5	F6	C1	C2	C3	C4	C5	C6
W_j	0.0476	0.0455	0.0516	0.0413	0.0658	0.0536	0.0383	0.0329	0.0345	0.0416	0.0326	0.0237
P unit	3	3	5	3	7	7	8.75	7	5	7	8.75	7
L unit	5	8.75	8.75	5	8.75	8.75	9.75	8.75	7	8.75	9.75	8.75
U unit	3	5	1.25	1.25	7	3	7	5	5	5	3	5

Table 10 Evaluation matrix for alternatives.

	P1	P2	P3	P4	P5	P6	P7	P8	L1	L2	L3	L4	L5	L6
W_j	0.0313	0.0252	0.0286	0.0286	0.0295	0.0316	0.0320	0.0292	0.0406	0.0388	0.0538	0.0459	0.0353	0.0406
P unit	1.25	5	8.75	8.75	5	3	7	7	8.75	7	5	5	3	5
L unit	5	7	8.75	7	3	1.25	7	1.25	8.75	8.75	5	5	5	7
U unit	0.25	1.25	5	5	1.25	0.25	3	1.25	5	7	3	3	3	3

Table 11 shows S and R values and also the best and worst values of S and R for the options. Final results of VIKOR method, is given in table 12. The best option in VIKOR method is the minimum value of Q which exists at least in one of S and R group. Ranking of three aircraft maintenance unit by VIKOR method, is as follows; L unit (Q_i = 0.0000) > P unit (Q_i = 0.7051) > U unit (Q_i = 1.0000). As the results show, L unit has higher performance

than two other units. P and U units should focus on their strengths and try to improve their weaknesses to have more presence in international competition that is constantly changing.

Table 11 The best and worst values of S and R of alternatives.

Alternatives	S	R
P unit	0.4500	0.0658
L unit	0.0784	0.0292
U unit	0.9842	0.0658
Max	0.9842	0.0658
Min	0.0784	0.0292

Table 12 The final results and ranks of alternatives using VIKOR method.

Alternatives	Q	Rank order
P unit	0.7051	2
L unit	0	1
U unit	1	3

Conclusion

Organizations performance evaluation is one of the most important principles of management for advancement of goals and strategies (Wu et al., 2009). Therefore, in this paper evaluation of aircraft maintenance units by using balanced scorecard methodology and FAHP-FVKIOR approach has been done. For this purpose, after specifying the performance evaluation criteria of the unit based on 4 BSC perspectives, by using FAHP and FVKIOR methods, the performance of three aircraft units has been measured. Results of the research show that aircraft maintenance units for advancement in their goals shall pay more attention to all perspective of BSC and specially to financial perspective.

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