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Performance Evaluation of Aircraft Maintenance Department Using Integration Fuzzy AHP and BSC Approach in Iran

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Abstract

In a competitive environment changes rapidly occur therefore managers of organizations facing some challenges such as identifying important factors affecting organizational optimum usage of available resources. Thus, organizational performance evaluation is a crucial task to do and sensitive process in any industry. The objective of this study is to construct an approach based on the balanced scorecard (BSC) and fuzzy analytic hierarchy process (FAHP) for evaluating the aircraft maintenance department in Iran. The BSC concept is applied to define the hierarchy with four major perspectives (i.e. financial, customer, internal business process, and learning and growth), and performance indicators are selected for each perspective. A Fuzzy AHP (FAHP) approach is then proposed in order to tolerate vagueness and ambiguity of information. A FAHP information system is finally constructed to facilitate the solving process. The results provide guidance to the aircraft maintenance department in Iran regarding strategies for improving department performance. The results show that financial indicator (0.305) and learning and growth indicator (0.255) have higher impacts on the objective. The constructed information system is suggested to be a good tool for solving other multiple-criteria decision-making problems.

Keywords: Fuzzy analytic hierarchy process (FAHP); Balanced Scorecard (BSC); Performance evaluation; aircraft maintenance evaluation.

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Introduction

In today's world, businesses are in search of alternative management systems in order to have an effective performance system. This search makes the strategic management systems and the systems that integrate those systems even more important (Erbasi and Parlakkaya, 2012).

The BSC developed by Kaplan and Norton in the 1990s is a performance measurement system evolved to become a complete strategic management system (Kaplan and Norton, 2001a, 2001b). The BSC has been very popular among practitioners as well as in the literature (Gomes et al., 2004; Neely, 2005; Nudurupati et al., 2010) (Chen et al., 2011).

The main contribution of the BSC is that it includes strategic objectives and performance measures that are not solely financial. The BSC considers four perspectives, where strategic objectives and performance measures are defined: (a) Financial, (b) Clients, (c) Internal processes, and (d) Learning and growth. There is a causal relationship among these perspectives: If the learning & growth perspective is improved, then the internal processes perspective will be improved. There is also a positive effect on client's perspective which will ultimately have an impact on the financial perspective (Quezada and López-Ospina According, 2014). To some studies, more than 80% of the top 1000 corporations in the world have adopted BSC, and BSC adoption has expanded in more and more countries over the last decade (Lin and Zhang, 2014).Examples of applications are the studies carried out by Lee et al. (2008) designed a fuzzy AHP and BSC approach for evaluating performance of IT department in the manufacturing industry in Taiwan. Wu et al. (2009) utilized a Fuzzy Multiple Criteria Decision Making (FMCDM) approach for banking performance evaluation. The Results obtained shows the proposed FMCDM evaluation model of banking performance using the BSC framework can be a used as an effective assessment tool. Cho and Lee (2011) described a web-based business process evaluation model based on BSC and fuzzy AHP for BPM. Sundharam et al. (2013) used integration BSC and AHP approach for a sustainable growth of manufacturing industries. Lin et al. (2013) built a performance evaluation system for operating room and used a fuzzy linguistic to convert the subjective cognition of managers into an information entity and confirmation of improvement. Research results assist the organization to evaluate and re vise corresponding strategy and generally to adopt modern management approaches in every day practice. Lin et al. (2014) investigated current status of BSC application and its impact on hospital performance in China. Quezada et al. (2014) presented a method to support the identification of the cause-effect relationships of strategic objectives of a strategy map of a balanced scorecard using AHP and linear programming (Chen et al., 2011).

In this research with considering to the potency points of BSC in strategic performance evaluation with combination to fuzzy AHP technique was used to evaluate the performance of the aircraft maintenance department in Iran.

Literature review

This section discusses the factors utilized for performance evaluation in the past as well as the results of this study. The sub-factors that affect the main factors are identified, and evaluation criteria developed there from (Chen et al., 2011).

Performance evaluation

The performance evaluation is a systematic review process carried out to help an organization reach a certain goal. Making performance evaluation part of the management and control system helps the organization to effectively manage its resources and measure its performance in relation to its goals (Wu and Hung, 2008). Traditional evaluation metrics are most often based only on financial performance and are thus limited in their assessment of overall performance (Booth, 1996). The traditional evaluation of financial performance is not an effective or comprehensive measure, nor is it a holistic evaluation concept. Kaplan and Norton (1992) proposed the balanced scorecard approach in order to overcome these shortcomings (Chen et al., 2011).

The balanced scorecard (BSC) and the analytic hierarchy process (AHP)

Focusing exclusively on traditional financial accounting measures, such as return on investment and payback period, has implications, and has been criticized as the root cause for many problems in industries (Hafeez, Zhang, & Malak, 2002). As managers stress on short-term financial performance metrics, they have a tendency to trade off actions, such as new product development, process improvements, human resource development, information technology and customer and market development that can bring in long-term benefits, for current profitability, and this limits the investments with future growth opportunities (Banker, Chang, Janakiraman, & Konstans, 2004). These actions of managers are a consequence of poorly designed performance measurement systems that only focus on short-term financial performance. In the attempt to solve the problem by supplementing financial measures with additional measures that can help evaluate the long-term performance of a firm, Kaplan and Norton introduced the BSC, a performance measurement framework that provides an integrated look at the business performance of a company by a set of measures, which includes both financial and non-financial metrics (Kaplan & Norton, 1992; Kaplan & Norton, 1993; Kaplan & Norton, 1996a). The name of BSC is with the intent to keep score of a set of measures that maintain a balance ‘‘between short- and long-term objectives, between financial and non-financial measures, between lagging and leading indicators, and between internal and external performance perspectives’’ (Kaplan & Norton, 1996b). Of the BSC’s four performance perspectives, one is a traditional financial performance group of items, and the other three involve non-financial performance measurement indexes: customer, internal business process, and learning and growth. The four perspectives are explained briefly as follows (Kaplan & Norton, 1996b):

• **Financial:** This perspective typically contains the traditional financial performance measures, which are usually related to profitability. The measurement criteria are usually profit, cash flow, ROI, return on invested capital (ROIC), and economic value added (EVA).

• **Customer:** Customers are the source of business profits; hence, satisfying customer needs is the objective pursued by companies. In this perspective, management determines the expected target customers and market segments for operational units and monitors the performance of operational units in these target segments. Some examples of the core or genetic measures are customer satisfaction, customer retention, new customer acquisition, market position and market share in targeted segments.

• **Internal business process:** The objective of this perspective is to satisfy shareholders and customers by excelling at some business processes that have the greatest impact. In determining the objectives and measures, the first step should be corporate value-chain analysis. An old operating process should be adjusted to realize the financial and customer dimension objectives. A complete internal business-process value chain that can meet current and future needs should then be constructed. A common enterprise internal value chain consists of three main business processes: innovation, operation and after-sale services.

• **Learning and growth:** The primary objective of this perspective is to provide the infrastructure for achieving the objectives of the other three perspectives and for creating long-term growth and improvement through people, systems and organizational procedures. This perspective stresses employee performance measurement, such as employee satisfaction, continuity, training and skills, since employee growth is an intangible asset to enterprises that will contribute to business growth. In the other three dimensions, there is often a gap between the actual and target human, system and procedure capabilities. Through learning and growth, enterprises can decrease this gap. The criteria include turnover rate of workers, expenditures on new technologies, expenses on training, and lead time for introducing innovation to a market.

The BSC objectives and measures are determined by organizational visions and strategies and are intended to measure organizational performance using the four perspectives. Kaplan and Norton (1996b) stress the importance of adhering to three principles in developing BSC: maintaining cause-and-effect relationships, comprising sufficient performance drivers and keeping a linkage to financial measures. They also emphasize that the BSC is only a template and must be customized for the specific elements of an organization or industry. Depending on the sector in which a business operates and on the strategy chosen, the number of perspectives can be enlarged, or one perspective can be replaced by the other. In addition, the BSC concept can be applied to measure, evaluate and guide activities in specific functional areas of a business, and even at the individual project level (Martinsons et al., 1999). Since its introduction, BSC has been adopted by many companies as a foundation for strategic management system. It has helped managers to align their businesses to new strategies towards growth opportunities based on more customized, value-adding products and services and away from simply cost reduction (Martinsons et al., 1999).

The analytic hierarchy process (AHP) was first introduced by Saaty in 1971 to solve the scarce resources allocation and planning needs for the military (Saaty, 1980). Since its introduction, the AHP has become one of the most widely used multiple-criteria decision-making (MCDM) methods, and has been used to solve unstructured problems in different areas of human needs and interests, such as political, economic, social and

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management sciences. The procedures of the AHP involve six essential steps (Cheng, 1999; Chi & Kuo, 2001; Kang & Lee, 2006; Lee, Kang, & Wang, 2006; Murtaza, 2003; Zahedi, 1986) (Lee et al., 2008):

1. Define the unstructured problem and state clearly the objectives and outcomes.

2. Decompose the complex problem into a hierarchical structure with decision elements (criteria, detailed criteria and alternatives).

3. Employ pairwise comparisons among decision elements and form comparison matrices.

4. Use the eigenvalue method to estimate the relative weights of the decision elements.

5. Check the consistency property of matrices to ensure that the judgments of decision makers are consistent.

6. Aggregate the relative weights of decision elements to obtain an overall rating for the alternatives.

Performance evaluation framework and analytical method

The analytical structure of this research is illustrated in Figure 1. A performance analysis is conducted based on the selected evaluation criteria. The FAHP approach is employed to calculate the relative weights and rank and to improve of the performance evaluation indexes and determine the best practice (Wu et al., 2009).

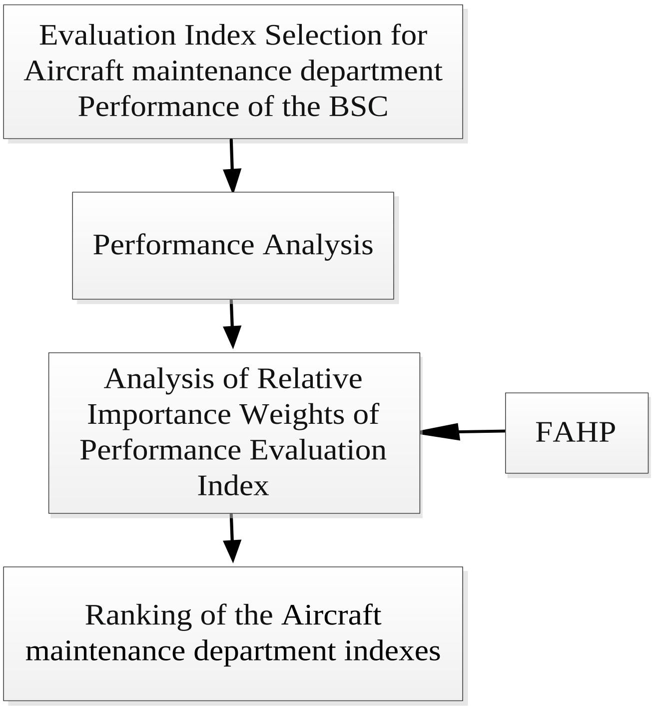

Figure 1 Performance evaluation framework of the research.

Aircraft maintenance

Maintenance may be seen as a kind of creation, science, and even an art. Throughout the years, the importance of maintenance functions and therefore of maintenance management has grown. Aerospace environment is much regulated in that every maintenance task has to respect very detailed process that ensures safety of flight. To achieve this goal, the maintenance process is tied to very stringent rules, which have been defined by regulation authorities. Maintenance is split into different categories according to time and required facilities (line maintenance, scheduled maintenance, or checks) or split by components (structure, components, power plants). A lot of literature is available from various resources in the field of maintenance management. Dekker and Scarf (1998) have presented various classifications of maintenance optimization models by analyzing 112 papers. In addition, prior to airline deregulation in 1978, airlines performed most of their own maintenance; however, since that time the practice of outsourcing maintenance has become widespread. Nowadays, it is common for airlines to perform line and light maintenance in-house to preserve flexibility in responding to simple maintenance needs and to outsource heavy maintenance and overhauls that require more specialized and costly equipment and training. Various approaches for measuring maintenance performance have also been reviewed [Tsang et al., 1999]. Aircraft maintenance is the overhaul, repair, inspection or modification of an aircraft or aircraft component. One of the most important factors influencing the success of an aircraft is the maintenance of its aircraft. Only when the fleet is in a technically excellent state of care can the flying operations be run punctually and profitably (Al Fazari, 2008).

Fuzzy set theory

Expressions such as ‘‘not very clear”, ‘‘probably so”, and ‘‘very likely”, are used often in daily life, and more or less represent some degree of uncertainty of human thought. The fuzzy set theory proposed by Zadeh (1965), an important concept applied in the scientific environment, has been available to other fields as well. Consequently, the fuzzy theory has become a useful tool for automating human activities with uncertainty-based information. Therefore, this research incorporates the fuzzy theory into the performance measurement by objectifying the evaluators’ subjective judgments (Wu et al., 2009).

Fuzzy Definitions

In the classical set theory, the truth value of a statement can be given by the membership function as $\mu_A(x)$:

$$\mu_A(x) = \begin{cases} 1 & if\ x \in A, \\ 0 & if\ x \notin A, \end{cases} \tag{1}$$

Fuzzy numbers are a fuzzy subset of real numbers, and they represent the expansion of the idea of a confidence interval. According to the definition by Dubois and Prade (1978), the fuzzy number $\tilde{A}$ is of a fuzzy set, and its membership function is $\mu_{\tilde{A}}(x)$: $R \rightarrow [0,1] (0 \leq \mu_{\tilde{A}}(x) \leq 1, x \in X)$, where x represents the criterion and is described by the following characteristics: (1) $\mu_{\tilde{A}}(x)$ is a continuous mapping from R (real line) to the closed interval [0,1]; (2) $\mu_{\tilde{A}}(x)$ is of a convex fuzzy subset; (3) $\mu_{\tilde{A}}(x)$ is the normalization

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of a fuzzy subset, which means that there exists a number x_0 such that $\mu_{\tilde{A}}(x_0) = 1$. For instance, the triangular fuzzy number (TFN), $\tilde{A} = (l, m, u)$, can be defined as Eq. (2) and the TFN membership function is shown in Fig. 2:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-l)/(m-l) & if\ l \le x \le m, \\ (u-x)/(u-m) & if\ m \le x \le u, \\ 0 & otherwise. \end{cases} \quad (2)$$

Based on the characteristics of TFN and the extension definitions proposed by Zadeh (1975), given any two positive triangular fuzzy numbers, $\widetilde{A_1} = (l_1, m_1, u_1)$ and $\widetilde{A_2} = (l_2, m_2, u_2)$, and a positive real number r, some algebraic operations of the triangular fuzzy numbers $\widetilde{A_1}$ and $\widetilde{A_2}$ can be expressed as follows (Wu et al., 2009):

Addition of two TFNs ⊕:

$$\widetilde{A_1} \oplus \widetilde{A_2} = (l_1 + l_2, m_1 + m_2, u_1 + u_2). \quad (3)$$

Multiplication of two TFNs ⊗:

$$\widetilde{A_1} \otimes \widetilde{A_2} = (l_1 l_2, m_1 m_2, u_1 u_2). \quad (4)$$

Multiplication of any real number r and a TFN ⊗:

$$r \otimes \widetilde{A_1} = (rl_1, rm_1, ru_1) \quad for \quad r > 0 \quad and \quad l_i > 0, \quad l_i > 0, \quad u_i > 0 \quad (5)$$

Subtraction of two TFNs ⊖:

$$\widetilde{A_1} \ominus \widetilde{A_2} = (l_1 - l_2, m_1 - m_2, u_1 - u_2) \quad for \quad l_i > 0, \quad l_i > 0, \quad u_i > 0 \quad (6)$$

Division of two TFNs ⊘:

$$\widetilde{A_1} \oslash \widetilde{A_2} = (l_1/u_2, m_1/m_2, u_1/l_2) \quad (7)$$

Reciprocal of a TFN:

$$\widetilde{A_1^{-1}} = (1/u_1, 1/m_1, 1/l_1) \quad for \quad l_i > 0, \quad l_i > 0, \quad u_i > 0 \quad (8)$$

Linguistic variable

Linguistic variables are variables whose values are words or sentences in a natural or artificial language. In other words, they are variables with lingual expression as their values (Hsieh et al., 2004; Zadeh, 1975). The possible values for these variables could be: ‘‘very dissatisfied”, ‘‘not satisfied”, ‘‘fair”, ‘‘satisfied”, and ‘‘very satisfied”. The evaluators are asked to conduct their judgments, and each linguistic variable can be indicated by a triangular fuzzy number (TFN) within the scale range of 0–100. An example of membership functions of five levels of linguistic variables is shown in Figure 2. For instance, the linguistic variable ‘‘Satisfied” can be represented as (60, 80,100). Besides, each evaluator can personally define his/her subjective range of linguistic variables. The use of linguistic variables is applied widely. In this paper, linguistic

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variables expressed by TFN are adopted to stand for evaluators' subjective measures to determine the degrees of importance among evaluation criteria and also assess the performance value of alternatives (Wu et al., 2009).

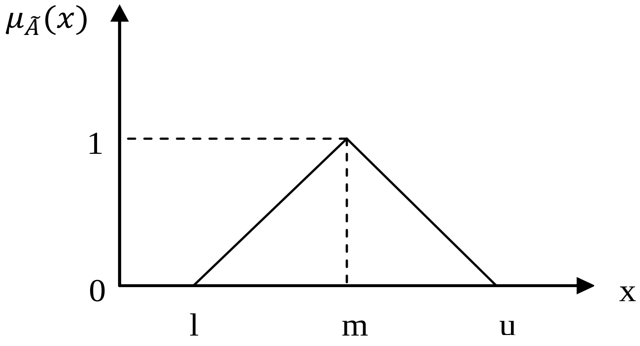

Figure 2 Membership function of the triangular fuzzy number.

Proposed approach

Consider a fuzzy prioritisation problem with n elements, the problem is to transform a fuzzy pairwise comparison matrix to the crisp priority vector $w = (w_1, w_2, \ldots, w_n)^T$. We use the fuzzy prioritisation method proposed by Mikhailov (2000, 2003) and construct a comparison matrix using $m \leq n(n-1)/2$ pairwise comparisons expressed with linguistic variables. The transformation of the linguistic judgments into triangular fuzzy numbers $\tilde{a}_{ij} = (l_{ij}, m_{ij}, u_{ij})$ results in the set $F = \{\tilde{a}_{ij} | i = 1,2,\ldots, n-1; j = 2,3,\ldots n, j > i\}$. If the pairwise comparisons are consistent, the priority ratios w_i / w_j should be close to *mij* and approximately within the lower and upper elements of the initial fuzzy judgments. We represent this preference as follows:

$$l_{ij} \lessapprox \frac{w_i}{w_j} \lessapprox u_{ij} \tag{9}$$

where the symbol $\lessapprox$ denotes the statement 'fuzzy less or equal to'. The degree to which the w_i/w_jratios satisfy the double-side inequality (9) is measured by the following membership function:

$$\beta_{ij}(w_i/w_j) = \begin{cases} \frac{(w_i/w_j - l_{ij})}{m_{ij} - l_{ij}}, & \frac{w_i}{w_j} \leq m_{ij} \\ \frac{(u_{ij} - w_i/w_j)}{u_{ij} - m_{ij}}, & \frac{w_i}{w_j} \geq m_{ij} \end{cases} \tag{10}$$

The maximum satisfaction level, $\beta_{ij} = 1$, is reached when $w_i/w_j = m_{ij}$. For $w_i/w_j < l_{ij}$ or $w_i > u_{ij}$, the function is negative and suggests unsuitability of the calculated weights. To measure the overall satisfaction level, the following aggregate membership function is defined:

$$\beta(w) = \min_{ij}\{\beta_{ij}(w) | i = 1, \ldots, n-1; j = 2, \ldots, n; j > i\} \tag{11}$$

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To maximize the satisfaction level, we use a mathematical program. Since the goal is the satisfactory calculation of all the $W_i s$, the model is defined as follows:

$$\max_{w \in S} \beta(w) = min_{ij}\{\beta_{ij}(w)\} \tag{12}$$

Where:

$$S = \{(w_1, w_2, \dots, w_n)\} | w_i > 0, \sum_{i=1}^{n} w_i = 1\} \tag{13}$$

It can easily be proved that β(w) is a convex set, so there is always a priority vector $w^* \in \ S$ that maximises the objective. The model can be represented as follows:

$Maximise\ \lambda$

$subject\ to$:

$$\lambda \le \beta_{ij}(w), i = 1,2, \dots, (n-1); j = 2, \dots, n; j > i$$
$$\sum_{l=1}^{n} w_l = 1, w_l > 0; 1,2, \dots, n \tag{14}$$

Model (14) can be further transformed into the following bilinear program:

$Maximise\ \lambda$

$subject\ to$:

$$(m_{ij} - l_{ij})\lambda w_j - w_i + l_{ij} w_j \le 0$$
$$(u_{ij} - m_{ij})\lambda w_j + w_i - u_{ij} w_j \le 0$$
$$\sum_{k=1}^{n} w_k = 1, w_k > 0;\ k = 1,2, \dots, n. \tag{15}$$

In this paper we use Lingo 11 software to obtain the optimal solution (λ^*, w^*). λ^* is the consistency measure of the fuzzy pairwise comparisons. A positive λ* indicates that all $\beta_{ij}(w^*)$ are positive and consequently $l_{ij} \le (w_j^* / w_j^*) \le u_{ij}$; $\forall\ i$ (i.e., the fuzzy judgements are consistent and a good set of weights can be derived from the pairwise comparison matrix). On the other hand, a negative λ^* shows that the double-side inequalities (9) are not satisfied and the fuzzy judgments are inconsistent (Tavana et al., 2013).

The proposed framework, as shown in Table 1, is comprised of five distinct but interrelated steps. Some steps in this table are further divided into a series of interrelated processes (Huang et al., 2008).

Step1. Decision problem: weighting the selection criteria.

Step2. Determining the Framework for personnel selection.

Step3. Setting up the decision hierarchy. The step is to structure the decision problem in a hierarchy as depicted in Figure 3.

Step4. Collecting the Data from the selection panel.

Step5. Employing the pair-wise comparisons. This step is the comparison of the alternatives and the criteria. They are compared in pairs with respect to each element of the next higher level. For this relative comparison, the fundamental scale

of Table 1 can be used. It allows expressing the comparisons in verbal terms which are then translated in the corresponding numbers.

Step6. Estimating relative weights of elements on each level in the hierarchy.

Step7. Calculating the degree of consistency λ^* in order to validate the results.

Step8. Calculating the relative weights of those ratings with acceptable degree of consistency for the selection criteria.

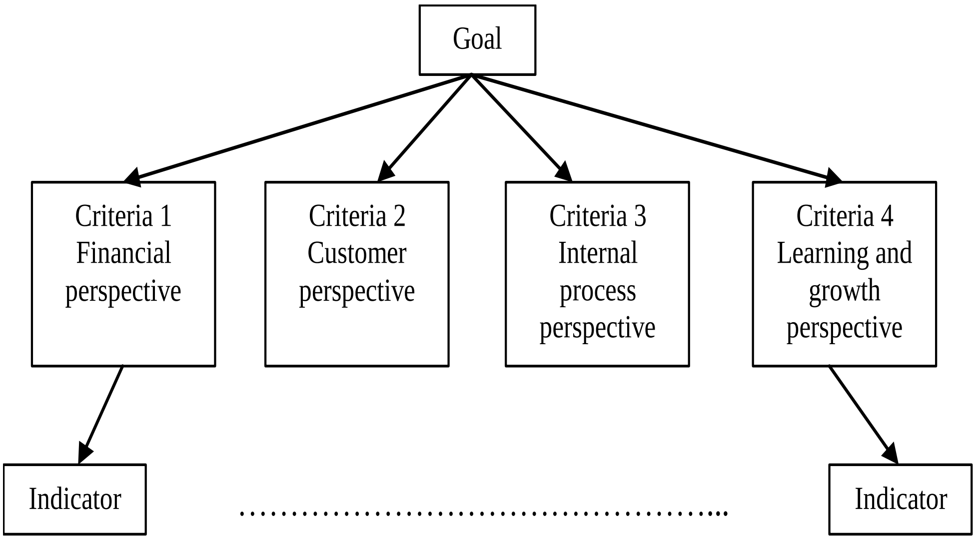

Figure 3 The basic structure of the hierarchy.

Table 1 The fuzzy representation of the relative importance grades 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)

Proposed model

Based on the concept of the BSC, reviewing aircraft maintenance department evaluation literature and interview with aircraft maintenance experts, an aircraft maintenance performance evaluation hierarchy is constructed as in Table 2. A

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questionnaire is designed with a conventional fuzzy AHP questionnaire format (pairwise comparison) based on the hierarchy. Thirty five questionnaires are distributed among senior managers of aircraft maintenance department in Iran. The experts' responses became equal to the matrix, so that the geometric mean of all the numbers and matrix calculations which have been used in the next parts (Lee et al., 2008).

Table 2 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)

Data analysis

Table 3 presents the result of the pairwise comparisons between the BSC criteria and their weights.

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, 5, 6 and 7 show the results of the pairwise comparisons between the BSC sub criteria and their Local weights.

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

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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

$\lambda = 0.240$

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

$\lambda = 0.34$

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The final fuzzy judgment of the aircraft maintenance department is deduced from the fuzzy criteria weights (Table 8).

In this case study, financial perspective, with a priority weight of 0.305, is the most important one in performance evaluation of the aircraft maintenance department, following by learning and growth, with a priority weight of 0.255. By the analysis of the priority weights of performance indicators as shown in Table 8, ‘‘Reducing costs (F5)’’ is the most important indicator with a priority weight of 0.0658 among all indicators. This means that the most important job of the aircraft maintenance department to reduce the costs. ‘‘Infrastructure development in science and technology (L3)’’ is ranked as the second weight of 0.0538 among all indicators. The third important indicator is ‘‘Developing income opportunities (F6)’’ with overall score of 0.0536, followed by ‘‘Optimal utilization of assets (F3)’’ with 0.0516. Note that due to the importance of the financial issue in aircraft maintenance department, this indicator is in the first rank. Customer indicator in all organizations is of particular importance, but most of the time, customers are fixed in this department. So it has the lowest rank among all perspectives, and is recommended that the aircraft maintenance department for attracting new customers and log in to global arena. Also it is recommended that this department focus on learning and growth indicator, as well as its internal business processes indicator.

Table 8 Overall weights and ranking of BSC performance evaluation indexes 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

BSC perspectives	Local weights	Overall weights	Rank
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

Conclusions

This paper proposes an approach based on the FAHP and BSC for evaluating the performance of the aircraft maintenance department in Iran. The analytic hierarchy is structured by the four major perspectives of the BSC including financial, customer, internal business process, and learning and growth, followed by performance indicators. As human decision-making process usually contains fuzziness and vagueness, the FAHP is adopted to solve the problem. A well-organized FAHP information system is constructed to facilitate the solving process.

The results show that financial indicator (0.305) and learning and growth indicator (0.255) have higher weights. This indicates that promoting financial and learning and growth indicators should be stressed by aircraft maintenance departments. For the performance indicators, ‘‘Reducing costs (F5)’’ (0.0658), ‘‘Infrastructure development in science and technology (L3)’’ (0.0538) and ‘‘Developing income opportunities (F6)’’ (0.0536) are the most important factors to be focused on.

Some distinguished contributions of this research are as follows:

1. This research adopts the concept of the BSC to develop a performance evaluation structure for aircraft maintenance department. Based on the literature review and interview with the experts in aircraft maintenance department, we finalize with twenty six most important performance indicators for aircraft maintenance department. These indicators can be a reference for aircraft maintenance department in performance evaluation.

2. This research bases on the fuzzy set theory and the AHP to propose a systematic performance evaluation model to provide guidance to aircraft maintenance department managers regarding performance evaluation and strategies for improving department performance.

3. The FAHP is constructed to assist the calculations of appropriate weightings for performance evaluation in aircraft maintenance department. The aircraft maintenance department can adopt FAHP for its routine performance evaluation of the department. On top of that, this is very user-friendly and can also be used for solving general MCDM problems with fuzzy nature in real practice and in research.

For future studies, applying other MCDM methods, such as ANP, TOPSIS, ELECTRE, VIKOR etc. in fuzzy environnement would be recommended. Moreover, application and developing of the proposed model in other industries can be another suggestion for improving the model.

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