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A fuzzy AHP and BSC approach for evaluating performance of IT department in the manufacturing industry in Taiwan

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Abstract

In this ever-changing world, information technology (IT) is a must for the survival of a company, and the functions of IT department is becoming increasingly important. The assessment of IT department is critical to understand how the department contributes to organizational and strategic goals. Because IT department performs many tasks that cannot simply be measured by monetary units, evaluation methods that solely rely on financial measures are not adequate. The objective of this study is to construct an approach based on the fuzzy analytic hierarchy process (FAHP) and balanced scorecard (BSC) for evaluating an IT department in the manufacturing industry in Taiwan. 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 IT departments in the manufacturing industry in Taiwan regarding strategies for improving department performance. 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; Information technology (IT)

1. Introduction

Information technology (IT) involves computers, software and services, but good IT must synthesize these elements to achieve the goal of an organization. As a demand to collect, process, store, and disseminate information grows, the functions of IT department is becoming increasingly important. Although businesses invest huge amount of intellectual and financial capital in a range of communication and information technologies and services, the results of some surveys revealed that some companies have started to freeze IT budgets because there are insufficient evidence of a return from the investments and IT applications seem to be simply a black hole (Martinsons, Davison, & Tse, 1999). The reason behind is that it is difficult for managers to demonstrate tangible returns on the resources expended to plan, develop, implement and operate computer-based information system (IS). Some frequently asked questions by the organizations are whether the investment in IT/IS is really worthwhile, whether the implemented IT application is a success, and whether the IT department functions productively. The measurement of the value of IT and the evaluation of IS performance, thus, become of great importance to managers.

Many methods and techniques have been suggested over the years to evaluate the investments in IT/IS or the performance of IT departments. However, well-known financial measures such as return on investment (ROI), internal rate of return (IRR), net present value (NPV) and payback period have been demonstrated to be inadequate (Abran & Buglione, 2003). In the assessment of IT/IS investments or departments, it is critical to understand how IT/IS contribute to organizational and strategic goals, and

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evaluation methods that rely on financial measures alone are not suitable for IT applications. The balanced scorecard (BSC), a performance measurement framework that provides an integrated look at the business performance of a company by a set of both financial and non-financial measures, seems to be a good solution. However, conventional BSC does not consolidate these performance measures, and an incorporation of BSC and analytic hierarchy process (AHP) is an improvement. Since fuzziness and vagueness are common characteristics in many decision-making problems, a fuzzy AHP (FAHP) and BSC method should be able to tolerate vagueness or ambiguity, and therefore, is proposed in this research.

The remainder of this paper is organized as follows. Section 2 briefly introduces the BSC and AHP. Section 3 goes over the fuzzy set theory. Section 4 reviews the incorporation of BSC with other methodologies and the application of the BSC in IT/IS field. Section 5 is the proposed model, in which a FAHP and BSC method is proposed, a FAHP information system is constructed, and the performance evaluation for IT department is carried out. Some conclusion remarks are made in the last section.

2. 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). Such 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). BSC software programs have even been developed to extract data from computer-based information system (IS) to obtain required performance indices.

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 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):

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.

3. Fuzzy set theory

Zadeh in 1965 introduced fuzzy set theory to solve problems involving the absence of sharply defined criteria (Zadeh, 1965). If uncertainty (fuzziness) of human decision-making is not taken into account, the results can be misleading. A commonality among terms of expression, such as ‘‘very likely’’, ‘‘probably so’’, ‘‘not very clear’’, ‘‘rather dangerous’’ that are often heard in daily life, is that they all contain some degree of uncertainty (Tsaur, Tzeng, & Wang, 1997; Tsaur, Chang, & Yen, 2002). Fuzzy theory thus is used to solve such kind of problems, and it has been applied in a variety of fields in the last four decades. Theory of fuzzy sets has evolved in various directions, and two distinct directions are: treating fuzzy sets as precisely defined mathematical objects subject to the rules of classical logic, and the linguistic approach. The underlying logic of linguistic approach is that the truth-values are fuzzy sets and the rules of inference are approximate rather than exact (Gupta, Saridis, & Gaines, 1977).

A triangular fuzzy number, a special case of a trapezoidal fuzzy number, is very popular in fuzzy applications. As shown in Fig. 1, the triangular fuzzy number $\widetilde{M}$ is represented by (a, b, c), and the membership function is defined as

$$\mu_{\widetilde{M}}(x) = \begin{cases} \frac{x-a}{b-a}, & a \leqslant x \leqslant b \\ \frac{c-x}{c-b}, & b \leqslant x \leqslant c \\ 0, & \text{otherwise} \end{cases} \tag{1}$$

with $-\infty < a \leqslant b \leqslant c < \infty$.

The strongest grade of membership is parameter b, that is, $f_M(b) = 1$, while a and c are the lower and upper bounds.

An important concept of fuzzy sets is the α-cut. For a fuzzy number $\widetilde{M}$ and any number $\alpha \in [0, 1]$, the α-cut, C_α, is the crisp set (Klir & Yan, 1995):

$$C_\alpha = \{x|C(x) \geqslant \alpha\} \tag{2}$$

The α-cut of a fuzzy number $\widetilde{M}$ is the crisp set $\widetilde{M}^\alpha$ that contains all the elements of the universal set U whose membership grades in $\widetilde{M}$ are greater than or equal to the specified value of α, as shown in Fig. 2.

By defining the interval of confidence at level α, the triangular fuzzy number can be characterized as (Cheng, 1999; Cheng, 1996; Cheng & Mon, 1994):

$$\widetilde{M}^\alpha = [a^\alpha, c^\alpha] = [(b-a)\alpha + a, -(c-b)\alpha + c], \quad \forall\alpha \in [0, 1] \tag{3}$$

The distance between two triangular fuzzy numbers can be defined by the vertex method (Chen, 2000). Let $\widetilde{M}_1 = (a_1, b_1, c_1)$ and $\widetilde{M}_2 = (a_2, b_2, c_2)$ be two triangular fuzzy numbers, the distance between them is

$$d(\widetilde{M}_1, \widetilde{M}_2) = \sqrt{\frac{1}{3}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2]} \tag{4}$$

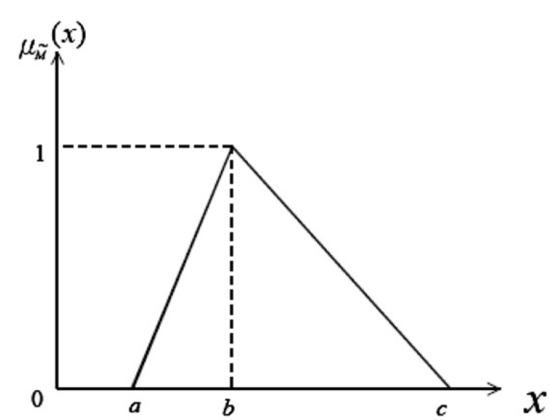


Fig. 1. Membership function of a triangular fuzzy number $\widetilde{M} = (a, b, c)$.

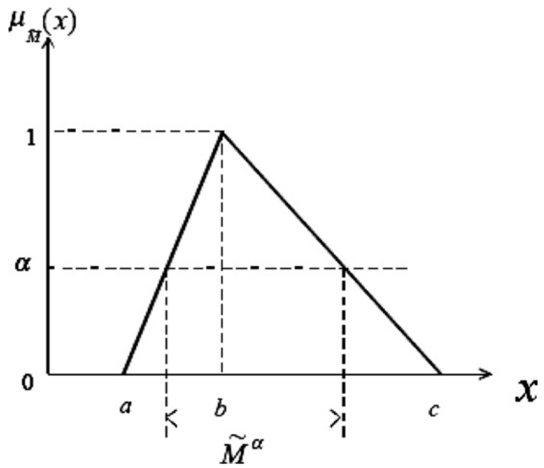


Fig. 2. α-cut of a triangular fuzzy number $\widetilde{M}$.

Many different methods have been devised to rank fuzzy numbers, and each method has its own advantages and disadvantages (Klir & Yan, 1995). A popular method is the intuition ranking method, which ranks triangular fuzzy numbers by drawing their membership function curves. A higher mean value and lower spread fuzzy number is preferred by human intuition (Lee & Li, 1988). Another popular fuzzy number ranking method is the α-cut method (Adamo, 1980). Centroid ranking method is also often used to rank fuzzy numbers (Yagar, 1978). A fuzzy mean and spread method was proposed by Lee and Li (1988) by using a generalized mean and standard deviation based on the probability measures of fuzzy events.

A good decision-making model needs to tolerate vagueness or ambiguity because fuzziness and vagueness are common characteristics in many decision-making problems (Yu, 2002). Since decision makers often provide uncertain answers rather than precise values, the transformation of qualitative preferences to point estimates may not be sensible. Conventional AHP that requires the selection of arbitrary values in pairwise comparison may not be sufficient, and uncertainty should be considered in some or all pairwise comparison values (Yu, 2002). Since the fuzzy linguistic approach can take the optimism/pessimism rating attitude of decision makers into account, linguistic values, whose membership functions are usually characterized by triangular fuzzy numbers, are recommended to assess preference ratings instead of conventional numerical equivalence method (Liang & Wang, 1994). As a result, the fuzzy AHP should be more appropriate and effective than conventional AHP in real practice where an uncertain pairwise comparison environment exists.

Many researches have been done with the application of fuzzy AHP, and different fuzzy AHP models are constructed (Laarhoeven & Pedrycz, 1983; Boender, de Graan, & Lootsma, 1989; Chen, 1996; Cheng, 1996; Cheng, 1999; Murtaza, 2003; Lee et al., 2006; Kang & Lee, 2006). While Ngai and Chan (2005) present a conventional AHP application to select the most appropriate tool to support knowledge management (KM), Wang and Chang (2006) construct an analytic hierarchy prediction model based on the consistent fuzzy preference relations to identify the essential success factors for an organization in KM implementation, KM project forecast, and identification of necessary actions before initiating KM. Bozbura, Beskese, and Kahraman (2006) propose a FAHP methodology to improve the quality of prioritization of human capital measurement indicators under fuzziness. Tzeng, Chiang, and Li (2006) design a generalized quantitative evaluation model, which considers the inter-affected relation between criteria and the fuzziness of subjective perception concurrently, to evaluate the effectiveness of e-learning. Factor analysis is applied to address the independent relations of evaluation criteria, and decision-making trial and evaluation laboratory (DEMATEL) method is used to deal with dependent relations of criteria. The AHP and the fuzzy integral methods are then used to obtain the final effectiveness of the e-learning programs.

4. The incorporation of BSC with other methodologies and the application of BSC in IT/IS field

Some recent researches related to the combination of the BSC and other methodologies are reviewed here. Banker et al. (2004) do a BSC analysis of performance metrics in the US telecommunications industry. Four performance metrics are used to fit the template of four perspectives of the BSC, i.e., return on assets (ROA), number of access lines per employee, percentage of digital access lines and percentage of business access lines for the financial, internal process, innovation and learning, and customer perspective, respectively. A data envelopment analysis (DEA) model is then constructed to investigate the frontier relationship between the financial performance metric (ROA) and three non-financial performance metrics. The results show that two of the three non-financial metrics do not require any tradeoff with the financial metric, while the third non-financial metric (percentage of business access lines) does require tradeoffs with the financial metric and must be included properly in the performance measurement and evaluation system. Ravi, Shankar, and Tiwari (2005) analyze alternatives in reverse logistics for end-of-life computers by an analytic network process (ANP) and BSC approach. The ANP structures the problem related to options in reverse logistics in a hierarchical form, and the dimensions of reverse logistics are taken from four perspectives derived from the BSC approach. With the ANP, the interdependencies among criteria, sub-criteria and determinants for the options can be considered. With the BSC, financial and non-financial, tangible and intangible, internal and external factors can be linked. As a result, a combination of BSC and ANP-based approach provides a more realistic, accurate and holistic framework for the problem.

The BSC has been utilized extensively in various fields, so as in the IT/IS field. Kaplan and Norton (1992) use an IT-company as an example to illustrate the use of the BSC by establishing a BSC framework, selecting a number of metrics, and setting a number of targets for top management. Willcocks and Lester (1994) tailor the BSC framework to the specific needs of IT investment evaluation in a major European ferry company. Martinsons (1992) and Martinsons et al. (1999) suggest the use of BSC to help managers evaluate IT investments and the performance of IS organizations, in a holistic manner. Abran and Buglione (2003) argue that the traditional BSC cannot integrate the perspectives automatically into a consolidated view and thus the frameworks do not tackle the contribution of each goal to the whole BSC. A multidimensional performance model for consolidating BSCs for information and communication technology organizations is proposed by using the quality factor + economic, social and technical dimensions (QEST) for the BSC. Milis and Mercken (2004) review the traditional capital investment appraisal techniques, such as payback period (PP), accounting rate of return (ARR)/ROI, IRR and NPV, for information and communication technology projects and discuss the drawbacks of these methods. A multi-layer evaluation process that uses a mixture of the BSC and multi-layer evaluation, is proposed by eliminating or diminishing the weaknesses of the conventional techniques.

Even though the BSC framework tackles performance at several levels, from the organizational level to the small business unit, and to the individual level, there are some disadvantages and pitfalls in the application. First of all, there are no generic measures or perspectives that fit all organizations or all business units (Milis & Mercken, 2004). The expertise and background of the users, therefore, are very valuable in setting the framework. Secondly, with a variety of quantitative indicators, the BSC does not consolidate these performance values, neither for the individual perspectives nor for their consolidation (Abran & Buglione, 2003). The BSC does not provide a technique to estimate quantitatively how much each perspective contributes, either in relative or in absolute terms, nor does it estimate the relative importance of indicators under the same perspective (Abran & Buglione, 2003). The consolidation, in practice, has to be carried out intuitively by the users of the BSC (Abran & Buglione, 2003). AHP, as introduced in Section 2, can be combined with the BSC to solve the aforementioned problems.

Under the AHP, decision makers need to structure the hierarchy which reflects the criteria that can achieve the goal. Incomplete hierarchy may lead to unfitting conclusions. Since the BSC completely estimate the performance of enterprises in four perspectives, a combination of BSC and AHP can solve the performance problem more credibly. Stwart and Mohamed (2001) propose a tiered BSC framework for IT/IS performance evaluation in construction by applying AHP and multi-attribute utility theory (MAUT). The AHP is used to structure the hierarchy and relative weightings of performance perspectives, indicators and measures, and MAUT is adopted to facilitate the obtained performance measurements to commensurable units. The overall IT/IS performance improvement measure at each decision-making tier (i.e., enterprise, business unit, construction project) can be generated. Clinton, Webber, and Hassel (2002) use the AHP in implementing a BSC. The first level of a BSC hierarchy contains the four BSC perspectives, and the second level of the hierarchy contains the metrics used within each perspective. The AHP can be used to select the metrics of the BSC and to help understand the relative importance of metrics. Sohn, You, Lee, and Lee (2003) investigates the relationship among corporate strategies, environmental forces, and the BSC performance measures. The AHP is applied to calculate the relative weights for each performance measure. Searcy (2004) also suggests the integration of the AHP and BSC to investigate the degree of alignment between management's ranking of BSC perspectives and the company's strategic initiatives. Chiang (2005) proposes a dynamic approach based on AHP and BSC for vendor selection problems. The BSC is applied to define the four perspectives of supplier selection, and attributes are extended form the perspectives. The structure is treated as the hierarchy that is next used by the AHP, and the scores of attributes and alternatives can be changed in a long-term period.

5. Proposed model

In this research, we first base on the four perspectives of the BSC to prepare a list of performance evaluation indicators, and then have an interview with the experts in IT departments of manufacturing companies in Taiwan to modify the list. A questionnaire is designed using the conventional AHP questionnaire format, and the four perspectives of the BSC and the selected performance indicators are included. The questionnaire is distributed to senior managers of the IT departments in the manufacturing industry, and the feedbacks are analyzed through a constructed FAHP program to obtain the relative importance of the four perspectives and the relative importance of the key performance indicators under each perspective. The results can provide some suggestions to IT departments of manufacturing companies in developing future department strategies, development objectives and performance evaluation.

5.1. Data collection

Based on the concept of the BSC, review of IT performance evaluation literature and interview with IT experts, an IT performance evaluation hierarchy is constructed as in Table 1. A questionnaire is designed with a conventional AHP questionnaire format (nine-point scale and pairwise comparison) based on the hierarchy. Forty questionnaires are distributed to senior managers of IT departments in the manufacturing industry in Taiwan, and the number of valid questionnaires is 31 (78%).

Table 1
Performance evaluation hierarchy of IT departments in manufacturing industry

Goal	Perspectives	Performance indicators
Performance evaluation of IT departments	Financial	Return on investment (ROI) or net present value (NPV)
		IT purchase cost
		Communication/network expense
	Customer	Internal satisfaction
		Maintenance time of PC
		System utilization rate
		Accuracy and timeliness of information
	Internal business	Average capacity and stability of the system
		Number and quality of internal process simplification
		Percentage and timeliness of solving problems
		On time rate of completing projects
	Learning and growth	Innovation on old systems
		Development of new systems
		Training number and hours of IT personnel

5.2. Fuzzy analytic hierarchy process (FAHP)

FAHP is used to generate the weighting of the four perspectives of the BSC and the weighting of the performance indicators. There are six essential steps:

1. Construct the hierarchical structure with decision elements (e.g., criteria and detailed criteria). Each decision maker is asked to express relative importance of two decision elements in the same level (e.g. two criteria) by a nine-point scale. Collect the scores of pairwise comparison, and form pairwise comparison matrices for each of the K decision makers.
2. Analyze consistency. The priority of the elements can be compared by the computation of eigenvalues and eigenvectors:

$$R \cdot w = \lambda_{\max} \cdot w \tag{5}$$

where w is the eigenvector, the weight vector, of matrix R, and $\lambda_{\max}$ is the largest eigenvalue of R.
The consistency property of the matrix is then checked to ensure the consistency of judgments in the pairwise comparison. The consistency index (CI) and consistency ratio (CR) are defined as (Saaty, 1980):

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{6}$$

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

where n is the number of items being compared in the matrix, and RI is random index, the average consistency index of randomly generated pairwise comparison matrix of similar size, as shown in Table 2. As suggested by Saaty (1994), the upper threshold CR values are 0.05 for a 3×3 matrix, 0.08 for a 4×4 matrix, and 0.10 for larger matrices. If the consistency test is not passed, the original values in the pairwise comparison matrix must be revised by the decision maker.
3. Construct fuzzy positive matrices. The scores of pairwise comparison are transformed into linguistic variables, which are represented by positive triangular fuzzy numbers listed in Table 3. According to Buckley (1985), the fuzzy positive reciprocal matrix can be defined as:

$$\widetilde{R}^k = [\tilde{r}_{ij}]^k \tag{8}$$

where
$\widetilde{R}^k$: a positive reciprocal matrix of decision maker k;
$\tilde{r}_{ij}$: relative importance between decision elements i and j;
$\tilde{r}_{ij} = 1,\ \forall i = j$; and
$\tilde{r}_{ij} = \frac{1}{\tilde{r}_{ji}},\ \forall i, j = 1, 2, \ldots.., n$.
4. Calculate fuzzy weights. Based on the Lambda–Max method proposed by Csutora and Buckley (2001), calculate the fuzzy weights of decision elements. The procedures are:
   - Apply α-cut. Let $\alpha = 1$ to obtain the positive matrix of decision maker k, $\widetilde{R}_b^k = (\tilde{r}_{ij})_b^k$, and let $\alpha = 0$ to obtain the lower bound and upper bound positive matrices of decision maker k, $\widetilde{R}_a^k = (\tilde{r}_{ij})_a^k$ and $\widetilde{R}_c^k = (\tilde{r}_{ij})_c^k$. Based on the weight calculation procedure proposed in AHP, calculate weight matrix,

Table 3
Triangular fuzzy numbers

Linguistic variables	Positive triangular fuzzy numbers	Positive reciprocal triangular fuzzy numbers
Extremely strong	(9,9,9)	(1/9,1/9,1/9)
Intermediate	(7,8,9)	(1/9,1/8,1/7)
Very strong	(6,7,8)	(1/8,1/7,1/6)
Intermediate	(5,6,7)	(1/7,1/6,1/5)
Strong	(4,5,6)	(1/6,1/5,1/4)
Intermediate	(3,4,5)	(1/5,1/4,1/3)
Moderately strong	(2,3,4)	(1/4,1/3,1/2)
Intermediate	(1,2,3)	(1/3,1/2,1)
Equally strong	(1,1,1)	(1,1,1)

Table 2
Random index (RI) (Saaty, 1980)

N	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.19	1.51	1.48	1.56	1.57	1.59

$W_b^k = (w_i)_b^k$, $W_a^k = (w_i)_a^k$ and $W_c^k = (w_i)_c^k$, $i = 1, 2, \ldots, n$.

- In order to minimize the fuzziness of the weight, two constants, M_a^k and M_c^k, are chosen as follows:

$$M_a^k = \min\left\{\frac{w_{ib}^k}{w_{ia}^k} | 1 \leqslant i \leqslant n\right\} \tag{9}$$

$$M_c^k = \max\left\{\frac{w_{ib}^k}{w_{ic}^k} | 1 \leqslant i \leqslant n\right\} \tag{10}$$

The upper bound and lower bound of the weight are defined as

$$w_{ia}^{*k} = M_a^k w_{ia}^k \tag{11}$$

$$w_{ic}^{*k} = M_c^k w_{ic}^k \tag{12}$$

The upper bound and lower bound weight matrices are

$$W_a^{*k} = (w_i^*)_a^k, \quad i = 1, 2, \ldots, n \tag{13}$$

$$W_c^{*k} = (w_i^*)_c^k, \quad i = 1, 2, \ldots, n \tag{14}$$

- By combining W_a^{*k}, W_b^k and W_c^{*k}, the fuzzy weight matrix for decision maker k can be obtained and is defined as $\widetilde{W}_i^k = (w_{ia}^{*k}, w_{ib}^k, w_{ic}^{*k}), i = 1, 2, \ldots, n$.

5. Integrate the opinions of decision makers. Geometric average is applied to combine the fuzzy weights of decision makers

$$\overline{\widetilde{W}}_i = \left(\prod_{k=1}^{K} \widetilde{W}_i^k\right)^{\frac{1}{K}}, \quad \forall\, k = 1, 2, \ldots, K \tag{15}$$

where
$\overline{\widetilde{W}}_i$: combined fuzzy weight of decision element i of K decision makers.
$\widetilde{W}_i^k$: fuzzy weight of decision element i of decision maker k.
K: number of decision makers.

6. Obtain final ranking. Based on the equation proposed by Chen (2000), a closeness coefficient is defined to obtain the ranking order of the decision elements. The closeness coefficient is defined as follows:

$$\mathrm{CC}_i = \frac{d^-\left(\overline{\widetilde{W}}_i, 0\right)}{d^*\left(\overline{\widetilde{W}}_i, 1\right) + d^-\left(\overline{\widetilde{W}}_i, 0\right)}, \quad i = 1, 2, \ldots, n$$

$$0 \leqslant \mathrm{CC}_i \leqslant 1 \tag{16}$$

where CC_i is the weight for decision element i, and

$$d^-\left(\overline{\widetilde{W}}_i, 0\right) = \sqrt{\frac{1}{3}[(\overline{W}_{ia} - 0)^2 + (\overline{W}_{ib} - 0)^2 + (\overline{W}_{ic} - 0)^2]}$$

$$d^*\left(\overline{\widetilde{W}}_i, 1\right) = \sqrt{\frac{1}{3}[(\overline{W}_{ia} - 1)^2 + (\overline{W}_{ib} - 1)^2 + (\overline{W}_{ic} - 1)^2]}$$

$d^-\left(\overline{\widetilde{W}}_i, 0\right)$ and $d^*\left(\overline{\widetilde{W}}_i, 1\right)$ are the distance measurement between two fuzzy numbers.

5.3. Construction of the FAHP information system

Computer software packages, such as the Expert Choice (Expert Choice, 2006), have been applied abundantly in solving AHP problems. However, in the authors' knowledge, there is no commercial software of FAHP that is currently available. Therefore, we construct a FAHP IS with a friendly interface by utilizing PowerBuilder and MySQL. PowerBuilder 10 (Sybase, 2006), an industry-leading 4GL rapid application development (RAD) tool provided by Sybase, is used for the system construction since it increases developer productivity through tight integration of design, modeling, development, and management. MySQL 5.0 (MySQL, 2006), one of the most popular open source databases, is also adopted because it gives an array of new enterprise features to make more productive developing, deploying, and managing industrial strength applications. Prototyping is also employed to help the authors to build an IS that is intuitive and easy to manipulate by end users. An important thing to mention is that this developed FAHP IS not only can solve the stated problem in this research, it can also be used for solving general MCDM problems.

The performance evaluation information system is developed through the design flowchart as shown in Fig. 3. With a repetitive testing on the prototype, the performance evaluation system is finally developed, and consists of five subsystems: project, evaluator, information analysis, information query, and end user management. The functions of the subsystems are briefly explained here:

- Project subsystem
  1. Add a new project: A new project can be added, including project name, evaluation purpose, criteria, and detailed criteria.
  2. Delete a project: A project that is no longer needed can be deleted, including all the content of the project.
- Evaluator subsystem
  1. Add a new evaluator: The basic information of a new evaluator is entered, such as name, affiliation, title, and contact number.
  2. Delete an evaluator: The basic information of an evaluator who is no longer required in the evaluation can be deleted.
  3. Modify evaluator information: The basic information of an evaluator can be modified.
- Information analysis subsystem
  1. Evaluation structure: The hierarchical structure of the problem is constructed.
  2. Data input: The responses of the questionnaire are stored, such as the relative importance between two indicators.
  3. Consistency test: Examine the consistency of the pairwise comparison matrices.
  4. Comparison matrix: Based on the input of the questionnaire information, fuzzy positive matrices are formed.

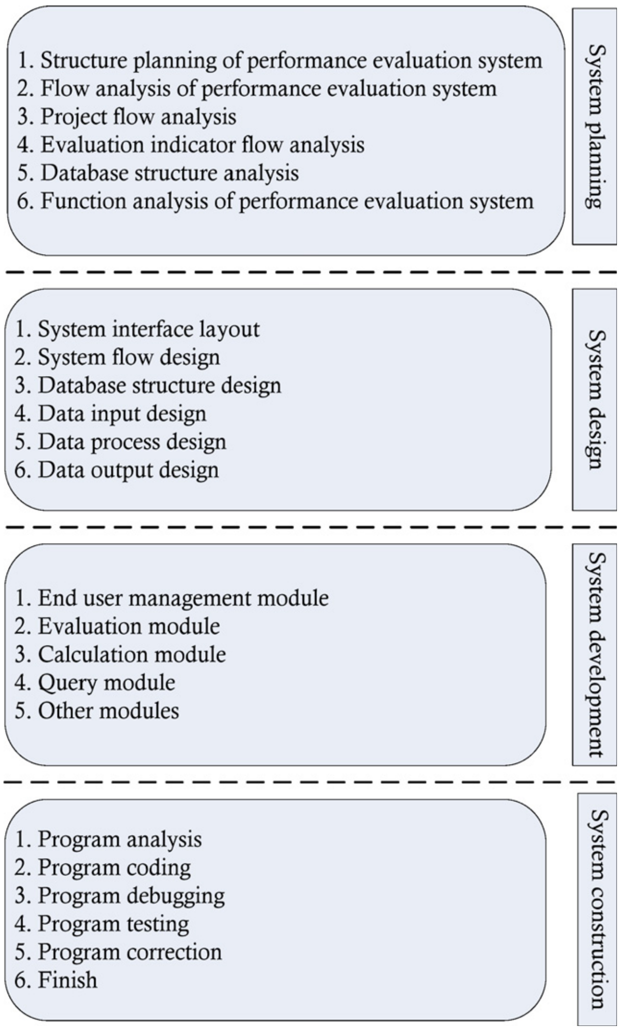


Fig. 3. System development life cycle.

5. Comparison weights: Based on FAHP concept, fuzzy pairwise comparison matrices are formed.
6. Fuzzy matrix: Obtain fuzzy weights of decision elements by integrating the opinions of decision makers.
7. Ranking: Obtain final ranking of decision elements.

- Information query subsystem
  1. Generate fuzzy weights: Fuzzy weights of decision elements, such as criteria and detailed criteria, are displayed.
  2. Generate ranking: Rankings of decision elements, such as criteria, detailed criteria and alternatives, are displayed.
- End user management subsystem
  1. Initialize database: Reset the database to the initial condition.
  2. Duplicate database: Make a copy of the current status of the database.
  3. User control: Set different authorization limits to different users based on the requirement.

5.4. Data input and analysis

The responses collected from questionnaires are input to the FAHP system, and the results are analyzed by the FAHP. Some of the processes are described as follows. A new project can be established by selecting "New" under the "File", and the name of the project can be entered as shown in Fig. 4. To delete a project, select "Delete".

The next step is to construct a hierarchy. Input the perspectives and performance indicators designed in the questionnaire into the "Evaluation structure" of "Information analysis subsystem". The four perspectives of the BSC are entered as criteria, and the performance indicators under each perspective are the detailed criteria. The results are as shown in Fig. 5. The pairwise comparison results of decision makers filled on the questionnaires are then input by selecting the number on the nine-point scale. An example of the pairwise comparison of perspectives from a decision maker is shown in Fig. 6.

After the relevant information is entered, the system can automatically generate pairwise comparison matrix. Maximum eigenvalue of the matrix is calculated by Eq. (5), and the consistency property of the matrix is checked by Eqs. (6) and (7). The results are shown in Fig. 7. If the consistency test is not passed, the questionnaire can either be revised by the decision maker or be disregarded. Fuzzy positive matrices based on the input questionnaire results are generated next by Eq. (8) and as shown in Fig. 8. Eqs. (9)–(14) are adopted next to calculate the comparison weights of decision elements. The fuzzy weights from different decision makers are finally combined by Eq. (15) to generate the overall fuzzy matrix, as shown in Fig. 9. The

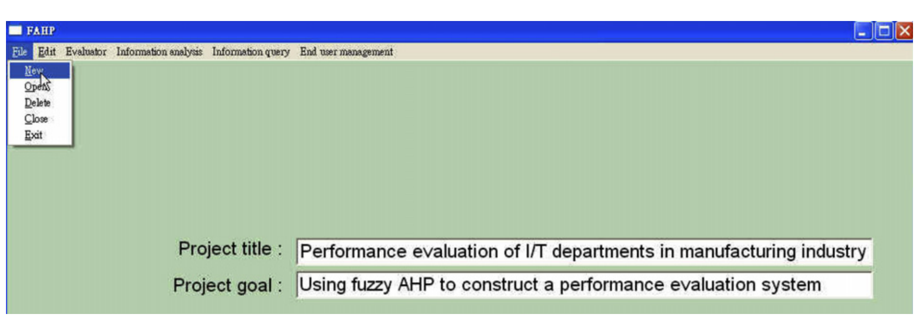


Fig. 4. Establish a new project.

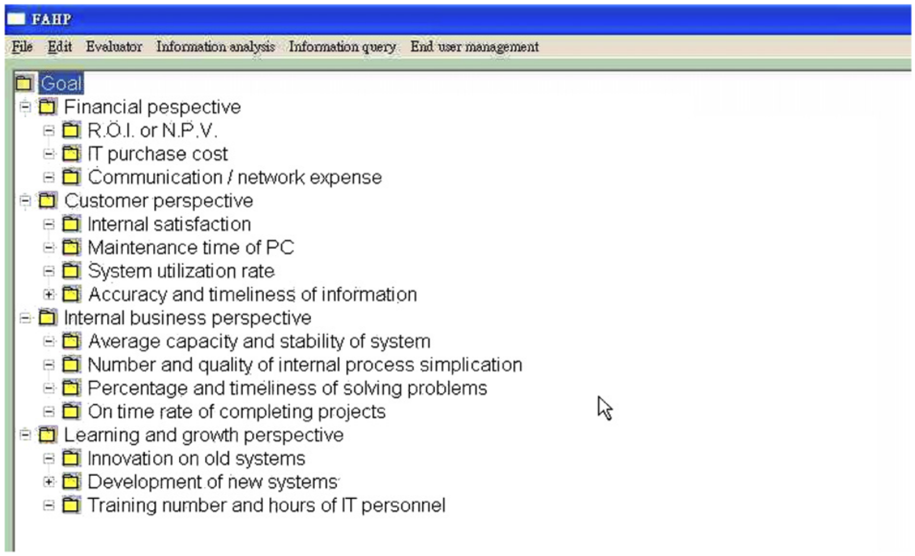


Fig. 5. Construct the hierarchy.

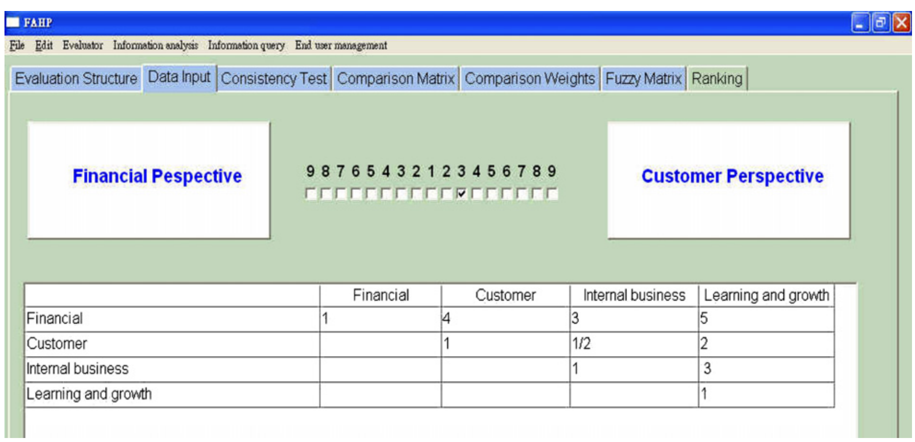


Fig. 6. Input questionnaire results.

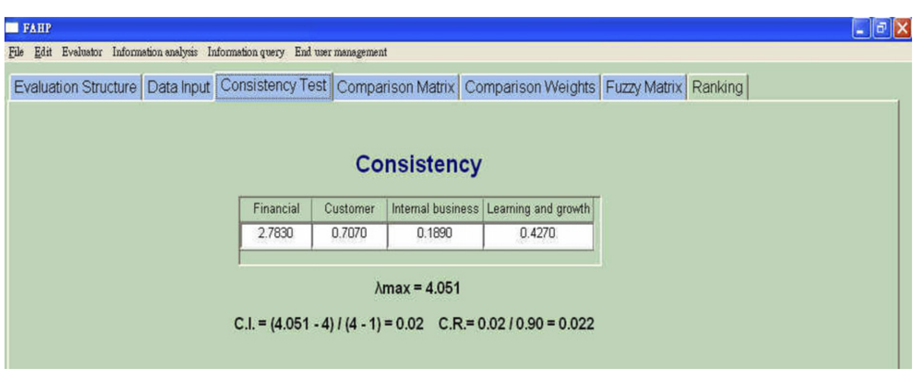
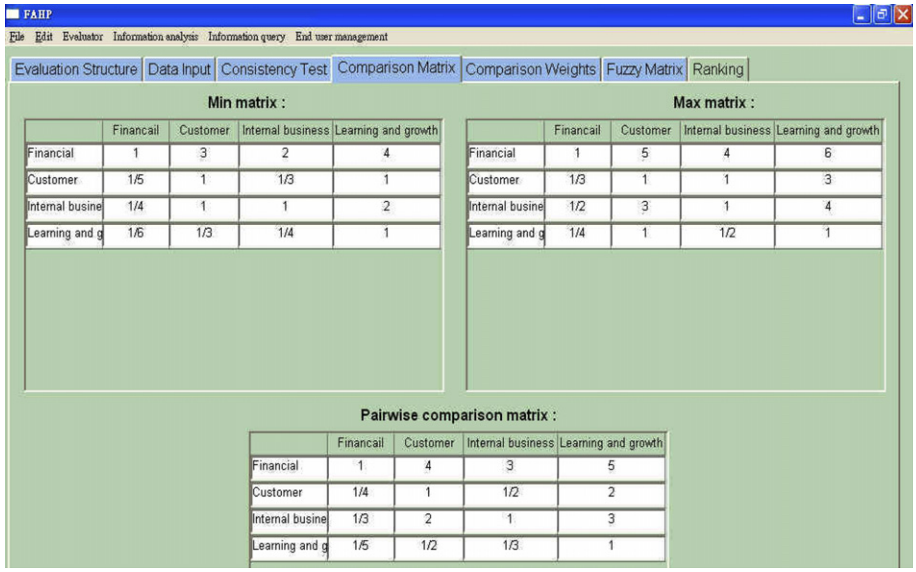


Fig. 7. Consistency test.

final priority weights and ranking are obtained by Eq. (16), as shown in Fig. 10.

In this case study, *customer*, with a priority weight of 0.378, is the most important perspective in performance evaluation of IT department in manufacturing industry, following by *internal business process*, with a priority weight of 0.299. With the analysis of the priority weights of performance indicators as shown in Fig. 11, “accuracy



Min matrix :

	Financail	Customer	Internal business	Learning and growth
Financial	1	3	2	4
Customer	1/5	1	1/3	1
Internal busine	1/4	1	1	2
Learning and g	1/6	1/3	1/4	1

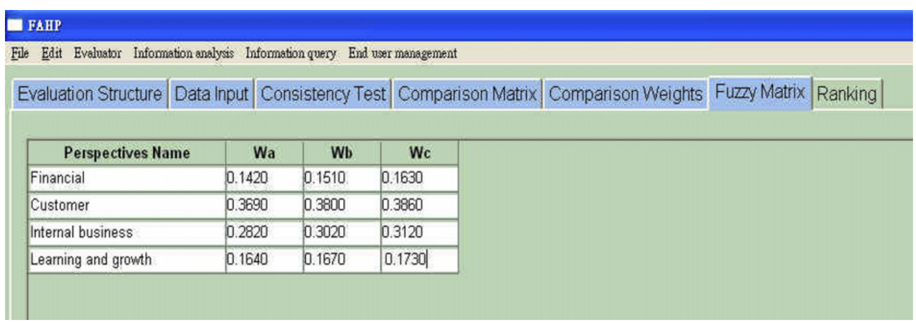
Max matrix :

	Financail	Customer	Internal business	Learning and growth
Financial	1	5	4	6
Customer	1/3	1	1	3
Internal busine	1/2	3	1	4
Learning and g	1/4	1	1/2	1

Pairwise comparison matrix :

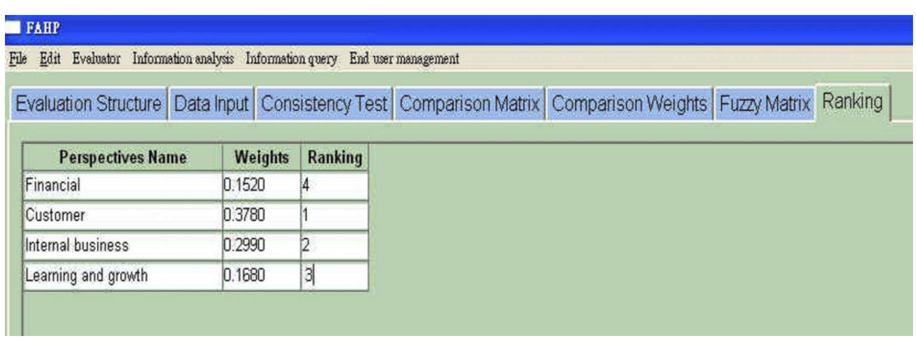
	Financail	Customer	Internal business	Learning and growth
Financial	1	4	3	5
Customer	1/4	1	1/2	2
Internal busine	1/3	2	1	3
Learning and g	1/5	1/2	1/3	1

Fig. 8. Comparison matrices.



Perspectives Name	Wa	Wb	Wc
Financial	0.1420	0.1510	0.1630
Customer	0.3690	0.3800	0.3860
Internal business	0.2820	0.3020	0.3120
Learning and growth	0.1640	0.1670	0.1730

Fig. 9. Overall fuzzy weights.



Perspectives Name	Weights	Ranking
Financial	0.1520	4
Customer	0.3780	1
Internal business	0.2990	2
Learning and growth	0.1680	3

Fig. 10. Final weights and ranking of perspectives.

and timeliness of information'' is the most important indicator with a priority weight of 0.437 in the *customer* perspective (or 0.165 among all indicators). This means that the most important job of IT department is to provide required information accurately and rapidly. ''Internal satisfaction'' ranks the second both in the *customer* perspective and among all indicators with 0.258 (or 0.098 among all indicators). The third important indicator is ''average capacity and stability of the system'' with overall score of 0.095, followed by ''ROI or NPV'' with 0.092. Note that although financial issue is usually emphasized the most by management in practice, it has the lowest rank among all perspectives in IT department, and ''ROI or NPV'' only ranks the fourth among all indicators.

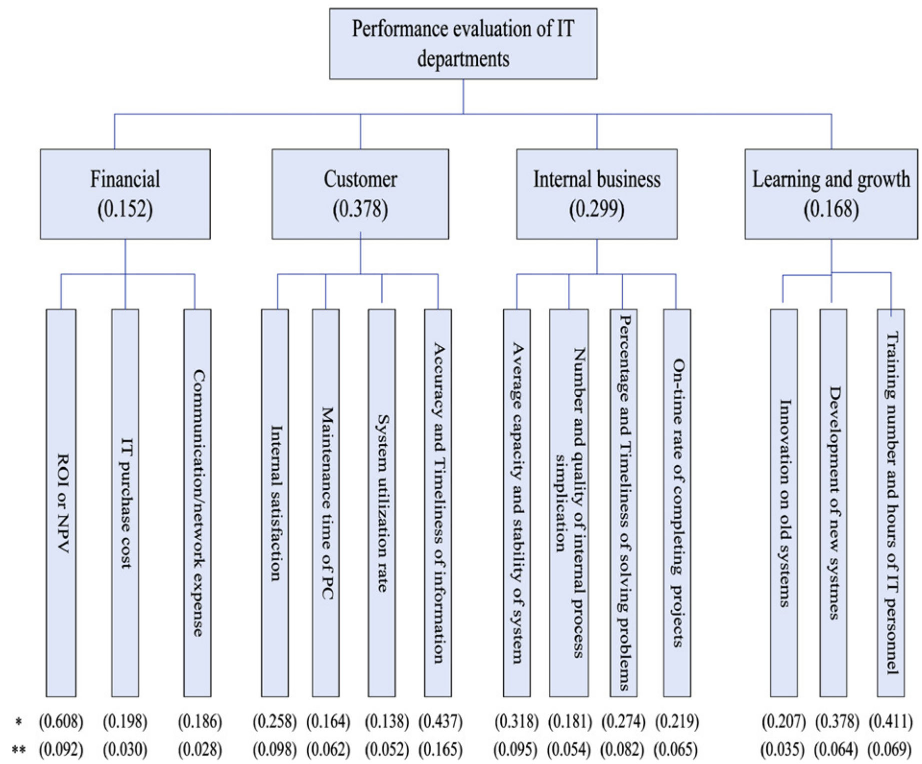


Fig. 11. Priorities weights for IT departments in manufacturing industry. *Relative priority weight of performance indicator under the same perspective. **Relative priority weight of performance indicator among all indicators.

6. Conclusions

This paper proposes an approach based on the FAHP and BSC for evaluating the performance of IT department in the manufacturing industry in Taiwan. 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. Because 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 *customer* (0.378) and *internal business process* (0.299) have higher weightings. This indicates that providing services to users and promoting internal business process improvement should be stressed by IT departments. For the performance indicators, ''accuracy and timeliness of information'' (0.165), ''internal satisfaction'' (0.098) and ''average capacity and stability of the system'' (0.095) 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 IT department in the manufacturing industry. Based on literature review and interview with experts in IT field, we finalize with fourteen most important performance indicators for IT departments. These indicators can be a reference for IT departments 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 IT department managers regarding performance evaluation and strategies for improving department performance.
3. A FAHP IS is constructed to assist the calculation of appropriate weightings for performance evaluation in IT department. An IT department can adopt this IS for routine performance evaluation of the department. On top of that, this IS is very user-friendly and can also be used for solving general MCDM problems with fuzzy nature in real practice and in research. Coding knowledge is not required for using this IS. The user only needs some basic knowledge of conventional AHP to construct the hierarchy and input the questionnaire, and the results can be obtained by clicking the icons. On the other hand, the IS can be easily altered by modifying the logic behind to adopt different FAHP models for research purposes.

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