A Selection Model for ERP System by Applying Fuzzy AHP Approach

Chi-Tai Lien* and Hsiao-Ling Chan

Department of Information Management
Ta Hwa Institute of Tachenology, Hsin-Chu, Taiwan, R.O.C.
*E-mail: chitailien@yahoo.com.tw

Abstract

The selection criteria of enterprise resource planning (ERP) system are numerous and fuzzy, so how to select an adequate ERP system is crucial in the early phase of an ERP project. We propose a fuzzy analytic hierarchy process (FAHP) model, which involves more comprehensive viewpoint for the software quality.

In this FAHP model, there are 32 criteria sifted out from product aspect and management aspect. Two practical cases are used for the practicability of the model; one is semiconductor industry and another is education industry. We find out that the cost issue is significantly important in both two cases. We also find that these two cases exist diverse priorities between weights of criteria.

Keywords: Enterprise resource planning (ERP) system, Software quality model, Fuzzy analytic hierarchy process (FAHP), Multi-criteria decision-making (MCDM).

1. Introduction

Enterprise Resource Planning (ERP) is a method for effective planning, and control for all resources needed to take, make, ship and account for customer orders in a manufacturing, distribution and service company (APICS Dictionary, 1998). For the improvement of computer hardware and software capability, ERP system had grown into an integrated software solution which is capable of running every function of an organization (Kapp, 2001).

To select an ERP product is a time-consuming task due to the limitations in available resources, the complexity of ERP software, and the diversity of alternatives (Wei and Wang, 2004). Thus, the ERP project should regard as a large project implementing and devote full participation in it. A comprehensively systematic selection policy for ERP system is crucial to the success of ERP project.

In this paper, we propose a fuzzy analytic hierarchy process (FAHP) method to evaluate the alternatives of ERP system. Our proposed model which considers software quality characteristics; besides it can also solve the multi-criteria decision-making (MCDM) problems and facilitates group fuzzy MCDM process.

Two empirical cases, one in semiconductor industry (company A) and another in education service industry (college T), demonstrate the practical viability of the model. Owing to different users requirements of information systems might exist interactions and trade-offs (Nixon, 2000). Both cases are also compared the similarities and dissimilarities between them.

2. Literature Review

The number of studies have explored various election methods of ERP system either qualitative or quantitative. There were a conceptual model for ERP package enhancement and a six-stage model to evaluate ERP software (Scott and Kaindl, 2000, Verville and Halingten, 2003). Owing to the essence of IT system, selection problem is a MCDM process. Several papers adopted analytic hierarchy process (AHP) to be the analytical tool (Schniderjans and Wilson, 1991, Wei et al., 2005). Lin (2002) and Luo and Strong (2004) studied the ERP evaluation models for universities.

Selection criteria of ERP system is also a crucial issue in ERP project. When implementing an ERP project, price and time are both the most important factors. Besides, the vender's support is also a crucial issue (Langenwalter, 2000). Except the investment cost of ERP project, the annual maintenance cost and human resource cost are also the potential expense for organizations (Butlar, 1999, Bingi et al., 1999).There was a ERP selection model containing three categories of selection attributes including project factors, software system factors and vender factors (Wei and Wang, 2004). The system integration between existing information systems and ERP system is a further technical problem which might complicate the entire ERP project (Holland and Light, 1999).

The earliest proposed prototype of software quality model is the McCall model which contains 11 criteria (McCall et al., 1977). Boehm et al. (1978) enlarged the characteristics of software and incorporates 19 criteria. These quality models are very similar to one another in many respects but differ mainly in terminology. Therefore, International Standard Organization (ISO) standardized these quality models and drew on the various quality models to produce a small set of six consistent characteristics, which give coverage of the main concepts of interest (International Standard 9126, 1991). The ISO 9126 software quality model is also been chosen to describe the software product characteristics in our proposed model.

Frequently, human judgments are often ambiguous and cannot estimate his/her preference with a crisp numerical value (Herrera and Herrera-Viedma, 2000). Fuzzy set theory is developed for solving problems in which description of activities and observations are imprecise, vague and uncertain. Since the fuzzy set theory incorporated into the traditional AHP (Buckley, 1985), FAHP were becoming a suitable tool to solve the real-world MCDM problems (Buyukozkan et al., 2004, Huang and Wu, 2005). FAHP had used to select e-marketplace software and evaluated the public transport system (Buyukozkan, 2004, Hsu, 1999). A fuzzy multi criteria group decision making approach was proposed to select configuration items for software development (Wang and Lin, 2003).

3. FAHP Model for ERP System Selection

The complete procedure of our proposed ERP selection model is shown in Fig. 1. The model involves two principle essentials which are presented as following sections. In section 3.1, the selection criteria of two aspects have been identified. The FAHP process and defuzzification policy are presented in section 3.2.

3.1 Selection Criteria Extraction

Criteria of Management Aspect

In section 2.2 as mentioned above, the generally selection criteria of ERP system contains three major criteria: vender factors, cost factors and time factors. By the way of literature review and deep interview with two project teams of company A and college T, we sift out four sub criteria of vender factors and four sub criteria of cost factors. And then we sort three time fences to be the sub criteria of time factors from a generally five-stage ERP project implementation road map (Fig.2).

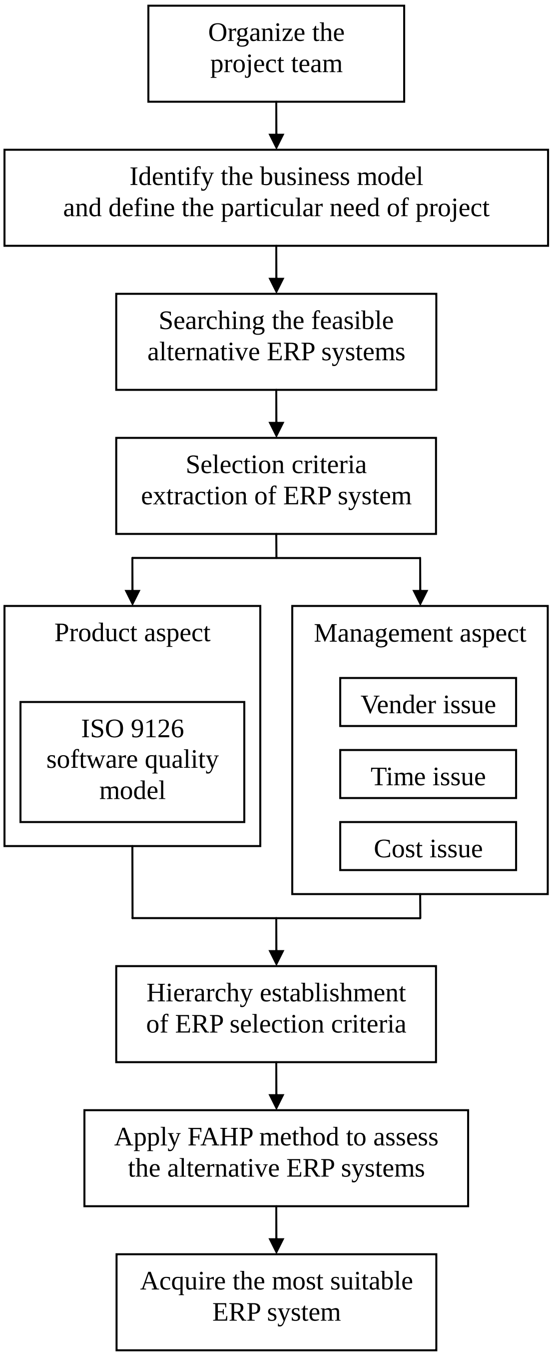

Fig.1. Comprehensive model for ERP system selection

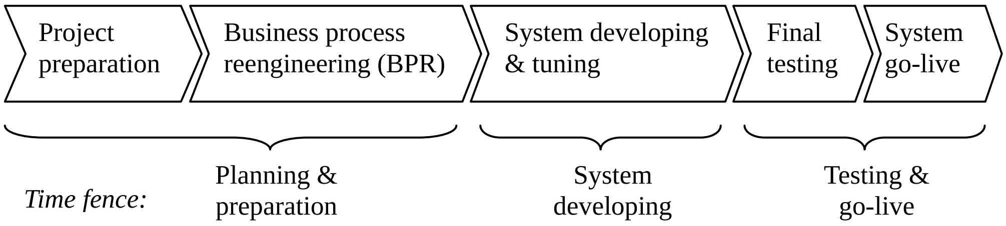

Fig.2. Generally ERP project implementation road map

Consequently, total 11 sub criteria have been decomposed from three major criteria. The 11 criteria are displayed as follows, and we categorize them to the management aspect.

(1) Sub criteria of vender factors: market share and reputation, industrial credential, service and support, training solution.
(2) Sub criteria of cost factors: software cost, hardware cost, annual maintenance cost, staff training cost.
(3) Sub criteria of time factors: time for planning and preparation, time for BPR and system tuning, time for testing and go-live.

Criteria of Product Aspect

The ISO 9126 software quality model is chosen to describe the ERP product characteristic and we categorize it as product aspect in the model. This quality model identifies six key quality attributes. The detailed characterization is presented as follows (Bache and Bazzana, 1994) (See Fig.3)

(1) Functionality

This attribute is defined as the degree to which the software functions satisfies stated or implied needs and can be broken down into five sub-characteristics as follows: suitability, accuracy, interoperability, compliance and security.

(2) Reliability

This attribute is defined as the capability of software that could maintain its level of performance under stated conditions for a stated period of time. It can be decomposed into three sub-characteristics as follows: maturity, fault tolerance and recoverability.

(3) Usability

This attribute is defined as the degree to which the software is available for use and can be broken down into three sub-characteristics as follows: understandability, learnability and operability.

(4) Efficiency

This attribute is defined as the degree to which the software makes optimal use of system resources. It can be decomposed into two sub-characteristics as follows: efficiency of time behavior and efficiency of resource behavior.

(5) Maintainability

This attribute is defined as the ease with which repair may be made to the software and can be broken down into four sub-characteristics as follows: analyzability, changeability, stability and testability.

(6) Portability

This attribute is defined as the ability of software that can be transferred from one environment to another. It can be decomposed into four sub-characteristics as follows: adaptability, installability, conformance and replaceability.

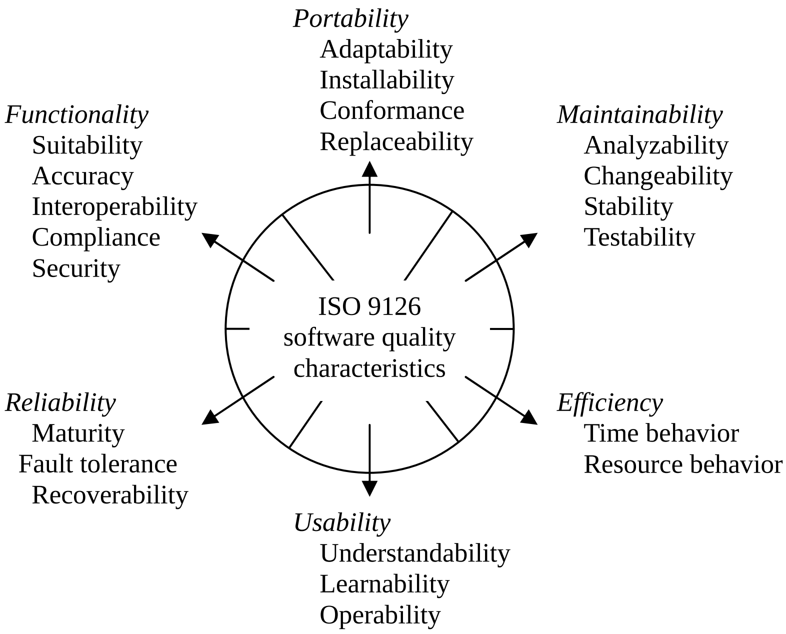

Fig.3. ISO 9126 software quality characteristics

3.2 FAHP Method and Defuzzification Policy

FAHP Stepwise Procedure

Step 1: Create the hierarchies
According to the problem characteristics, to decompose each attribute and build up the hierarchy structure, the 0^{th} layer represents the ultimate goal; the 1^{st} layer represents the primary aspects that affect the ultimate goal; the 2^{nd} layer represents the major decision criteria of the 1^{st} layer, and so on. The last layer represents the alternate choices of the feasible solutions.

Step 2: Create fuzzy pairwise comparison matrix
According to the layer structure built up in Step 1, the decision importance criteria converted into the semantic format were used to design polling questionnaires. The next phase was to convert the results of the questionnaire into fuzzy pairwise comparison matrix by using Saaty's 9 scales.

Step3: Group combination (unification, integration)
After creating the fuzzy pairwise comparison matrix, the geometric mean of each criteria in the matrix was calculated as Buckley suggested.

Step 4: Build up the fuzzy positive reciprocal matrix
After Step 3, obtaining the final calculated fuzzy numbers for each layer could form the fuzzy positive reciprocal matrix.

Step 5: Calculate the key factors' fuzzy weights
The formulas are suggested by Buckley's fuzzy AHP model.

Step 6: Hierarchy layer sequencing
In the final step, the sequential layers are linked together to calculate the final fuzzy weight values for each alternative.

Defuzzification Policy

We adopt the center of gravity method to be the defuzzification policy. The defuzzified number is calculated by formula (1).

$$U^*(C) = \frac{\int_{-c}^{c} C(z)zdz}{\int_{-c}^{c} C(z)dz} \qquad (1)$$

$U^*(C)$: is defined as the value within the range of variable v.

Where the area under the graph of membership function C is divided into two sub areas.

4. Applications: Two Practical Cases

In section 3.1, we classified two aspects of ERP selection criteria, product and management, respectively. For the product aspect, we introduced ISO 9126 software quality model including six major criteria and 21 sub criteria to be the assessing attributes. Further, three major criteria including 11 sub criteria in the management aspect were also discovered. Finally, the hierarchy structure of ERP selection model is established in Fig.4.

The ultimate goal and two aspects are set in 0^{th} layer and 1^{st} layer, respectively. The 2^{nd} and 3^{rd} layers belong to major criteria and sub criteria, and the feasible ERP solutions are put in the alternative layer. Two empirical cases in Taiwan, company A and college T respectively, belong to different industries were conducted to prove the practicality of our proposed model in sections 4.1 and 4.2.

4.1 Semiconductor Industry: Project of Company A

Background Illustration

Company A is an IC (integrated circuit) testing firm which is located in Hsinchu Industrial Park. This company provides a total semiconductor testing solution tests both wafers and IC chips for customers, so customer requirements are extremely important for this company. In order to enhance the competition in industry and meet the customer demand, company A determines to integrate the various information systems in every department within an ERP system.

Project Initiation and Identification

Firstly, the general manager of company A organizes the project team including nine senior managers in different departments: administration, finance, marketing, manufacturing, quality assurance, information technology and three product engineer departments. The general manager also identifies several distinctive needs and the qualified ERP systems should provide the following functions:

(1) The original MES (manufacturing execution system) must be integrated in the ERP system.

(2) The ERP system could expend to SCM (supply chain management) and link the APS (advanced planning and scheduling) system.

(3) The CRM (customer relationship management) function is an additional plus.

Searching the Feasible Solutions

Once the requirements and the particular functions of ERP system are well defined, the project team could search qualified ERP system solutions. After the preliminary elimination which is subjected to budget, time and system functions, four feasible ERP system alternatives are came out. Among the four candidate alternatives, vender I is a European firm, venders II is an American firm, vender III and IV are the local firms in Taiwan.

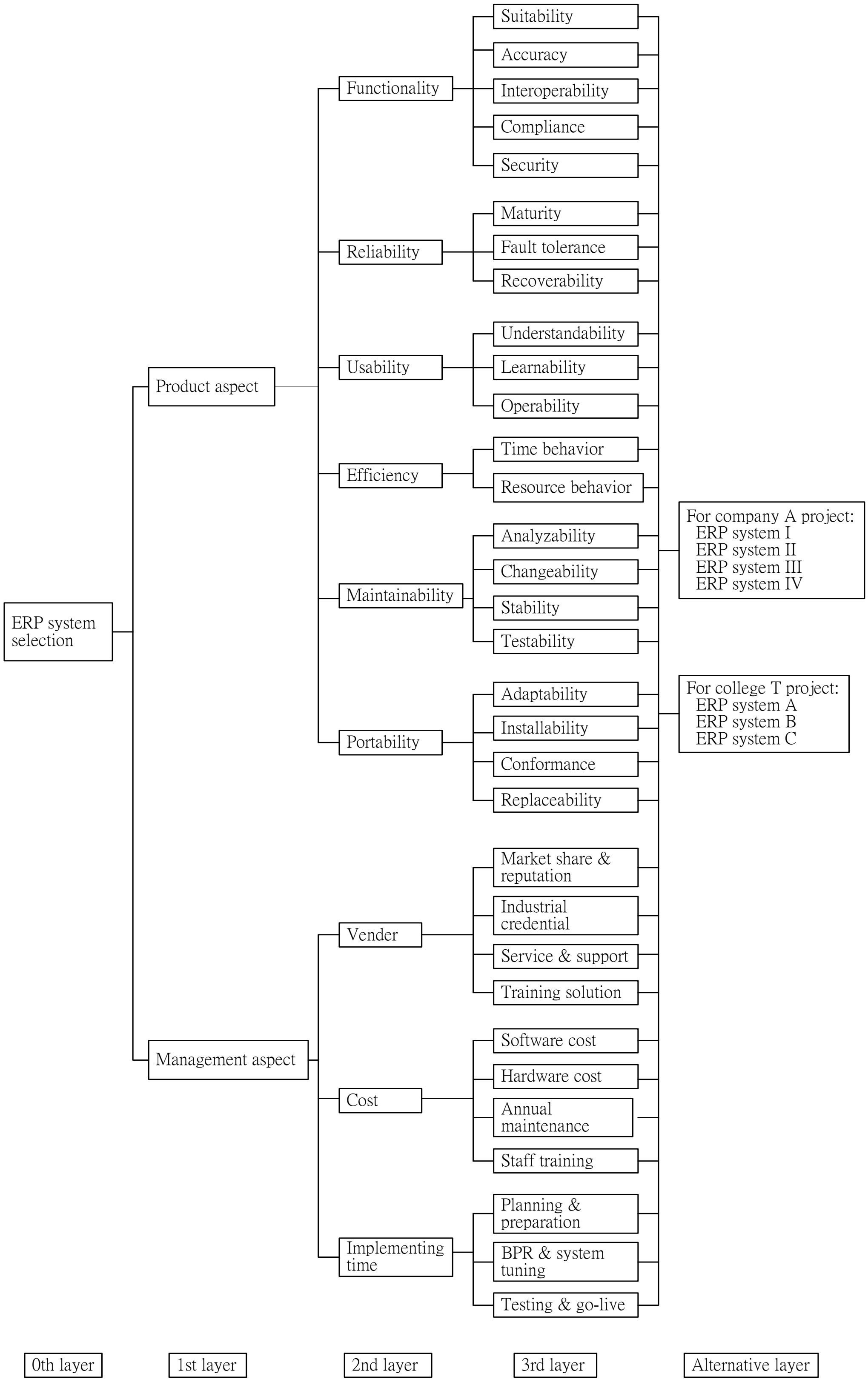

Fig.4. Hierarchy structure of ERP selection model

Hierarchy Establishment

The hierarchy structure with layer 0th, 1st, 2nd and 3rd for project of company A and the alternative layer is located four venders (i.e., I, II, III and IV) as shown in Fig.4.

Analyzing and Assessment Result

By using the hierarchy structure of total 32 criteria and following the stepwise FAHP method as mentioned above, the fuzzy weights of layer 1st, 2nd and 3rd are calculated by nine senior managers. After the fuzzy weights of each layer has been computed and linked together, the final fuzzy weights of entire 32 criteria is calculated as shown in Table 1. Table 2 lists the fuzzy scores for four alternatives relative to the first criteria "Suitability", and other fuzzy scores for four alternatives relative to remaining 31 criteria are computed as the same way. Ultimately, the final assessment result is presented as Table 3.

Table 1. Final fuzzy weights of entire 32 criteria for company A

Hierarchy of criteria			Fuzzy weight
Aspect	Major criteria	Sub criteria	
Product	Functionality	Suitability	(0.00945, 0.01840, 0.04122)
		Accuracy	(0.01037, 0.01984, 0.04394)
		Interoperability	(0.00516, 0.01174, 0.02541)
		Compliance	(0.00443, 0.01105, 0.02268)
		Security	(0.00804, 0.01469, 0.03137)
	Reliability	Maturity	(0.00495, 0.01238, 0.02826)
		Fault tolerance	(0.01282, 0.02490, 0.04902)
		Recoverability	(0.01546, 0.02965, 0.05912)
	Usability	Understandability	(0.00086, 0.00438, 0.01301)
		Learnability	(0.00284, 0.01090, 0.02822)
		Operability	(0.00233, 0.00905, 0.02372)
	Efficiency	Time behavior	(0.01771, 0.03476, 0.07355)
		Resource behavior	(0.01311, 0.02844, 0.06104)
	Maintainability	Analyzability	(0.01001, 0.01820, 0.03894)
		Changeability	(0.00885, 0.01720, 0.03638)
		Stability	(0.00492, 0.01138, 0.02742)
		Testability	(0.00800, 0.01576, 0.03446)
	Portability	Adaptability	(0.00761, 0.01472, 0.02946)
		Installability	(0.00429, 0.00928, 0.02146)
		Conformance	(0.00448, 0.00883, 0.02016)
		Replaceability	(0.00554, 0.01246, 0.02652)
Management	Vender	Market share & reputation	(0.01078, 0.02323, 0.04458)
		Industrial credential	(0.02372, 0.04165, 0.07429)
		Service & support	(0.02079, 0.03568, 0.06894)
		Training solution	(0.01596, 0.02919, 0.05686)
	Cost	Software cost	(0.02923, 0.05508, 0.09890)

	Hardware cost	(0.03512, 0.06885, 0.12242)
	Annual maintenance	(0.04195, 0.07573, 0.12578)
	Staff training	(0.04043, 0.07573, 0.11757)
Implementing time	Planning & preparation	(0.03279, 0.05779, 0.09987)
	BPR & system tuning	(0.04071, 0.07064, 0.12369)
	Testing & go-live	(0.07461, 0.12843, 0.23635)

Table 2. Fuzzy scores of each ERP system relative to the first criteria “Suitability” for company A

ERP system	Fuzzy score
I	(0.228, 0.287, 0.358)
II	(0.200, 0.249, 0.347)
III	(0.163, 0.231, 0.331)
IV	(0.149, 0.233, 0.315)

Table 3. Assessment result of each ERP system for company A

ERP system	Assessment result	Center of gravity	Rank
I	(0.09173, 0.24763, 0.64483)	0.32806	3
II	(0.10018, 0.25799, 0.66576)	*0.34131*	*1*
III	(0.09219, 0.24141, 0.63535)	0.32298	4
IV	(0.10033, 0.25297, 0.65540)	0.33623	2

Based on the assessment result in Table 3, ERP system II which is produced by an American vender is the dominant solution in the final rank. And the nine senior managers decide that system II is the most suitable decision for their company.

4.2 Education Industry: Project of College T

Background Illustration

College T is located in Hsinchu-county, over 300 faculties and 120 office staffs are employed by this college. The four schools including twelve departments and one institute contain more than 9,000 students. Owing to the growing of student numbers and complexity of managerial process, college T has decided to upgrade present information systems to an ERP system.

Project Initiation and Identification

The president of college T organizes the project team including eight members: four deans of each individual school, chief of computer and network center and three deans of academic affairs, student affairs and general affairs. Afterward the president identifies the business model of college T and defines five needs of the project. Thus, the qualified ERP systems for college T should provide the following functions:

(1)Function of faculty service and academic curriculum scheduling.
(2)Function of student service and management.
(3) Function of finance and accounting.
(4) Function of purchasing management.
(5) Function of facilities and material management.

Searching the Feasible Solutions

After the preliminary elimination, three feasible ERP system alternatives are sift out. Among the three candidate alternatives, vender A is a European firm, venders B and C are local firms in Taiwan.

Hierarchy Establishment

The hierarchy structure with layer 0^{th}, 1^{st}, 2^{nd} and 3^{rd} for the project of college T is the same as the project of company A. The alternative layer is located A, B and C three venders as shown in Fig.4.

Analyzing and Assessment Result

Using the identical FAHP method analysis, the fuzzy weights of each layer is calculated by eight decision makes. And the final fuzzy weights of entire 32 criteria are calculated as shown in Table 4. Table 5 lists the fuzzy scores for three alternatives relative to the first criteria “Suitability”, and the final assessment result is presented as Table 6.

Table 4. Final fuzzy weights of entire 32 criteria for college T

Hierarchy of criteria			Fuzzy weight
Aspect	Major criteria	Sub criteria	
Product	Functionality	Suitability	(0.01288, 0.02419, 0.05527)
		Accuracy	(0.01142, 0.02262, 0.05074)
		Interoperability	(0.00672, 0.01616, 0.03940)
		Compliance	(0.00568, 0.01459, 0.03400)
		Security	(0.01121, 0.02037, 0.04550)
	Reliability	Maturity	(0.00617, 0.01350, 0.03715)
		Fault tolerance	(0.00595, 0.01385, 0.03577)
		Recoverability	(0.00750, 0.01565, 0.04065)
	Usability	Understandability	(0.01361, 0.02756, 0.06219)
		Learnability	(0.01588, 0.03288, 0.07323)
		Operability	(0.01016, 0.02135, 0.05175)
	Efficiency	Time behavior	(0.00411, 0.01411, 0.02677)
		Resource behavior	(0.00688, 0.02352, 0.04419)
	Maintainability	Analyzability	(0.00702, 0.01929, 0.04299)
		Changeability	(0.00561, 0.01536, 0.03624)
		Stability	(0.00941, 0.02459, 0.05145)
		Testability	(0.00623, 0.01642, 0.03584)
	Portability	Adaptability	(0.00440, 0.01080, 0.02585)
		Installability	(0.00655, 0.01560, 0.03686)
		Conformance	(0.00374, 0.01018, 0.02549)
		Replaceability	(0.00428, 0.01142, 0.02705)
Management	Vender	Market share & reputation	(0.00711, 0.01953, 0.04763)
		Industrial credential	(0.02775, 0.05142, 0.09399)
		Service & support	(0.03009, 0.05425, 0.09754)

	Training solution	(0.02065, 0.04173, 0.08234)
Cost	Software cost	(0.04825, 0.07775, 0.13247)
	Hardware cost	(0.04539, 0.07775, 0.13101)
	Annual maintenance	(0.08638, 0.12959, 0.21916)
	Staff training	(0.03061, 0.06048, 0.10422)
Implementing time	Planning & preparation	(0.01829, 0.03446, 0.05888)
	BPR & system tuning	(0.01454, 0.03022, 0.05249)
	Testing & go-live	(0.02164, 0.03881, 0.06771)

Table 5. Fuzzy scores of each ERP system relative to the first criteria "Suitability" for college T

ERP system	Fuzzy score
A	(0.385, 0.421, 0.475)
B	(0.329, 0.397, 0.458)
C	(0.146, 0.182, 0.230)

Table 6. Assessment result of each ERP system for college T

ERP system	Assessment result	Center of gravity	Rank
A	(0.09408, 0.26963, 0.71560)	0.35977	3
B	(0.15831, 0.37621, 0.90522)	*0.47991*	*1*
C	(0.15444, 0.35416, 0.83721)	0.44860	2

As shown in Table 6, the local ERP system B is the dominant solution in the final rank. And the project team agrees that system B is the most suitable decision for college T.

4.3 Comparison between Company A and College T

According to final fuzzy weights of entire 32 criteria in Table 1 and Table 4, some discussions are presented as following:

2nd layer Comparison of the hierarchy

In the 2nd layer, the importance of the six attributes within product aspect exist few difference between industries. Although the functionality is the most important criterion for different organizations, the reliability issue is much more important in semiconductor industry than in education industry. It might be the unreliability derives more risk and loss in semiconductor industry than in education industry. Because ERP system is very expensive, cost issue of the management aspect is significantly more important than others in both organizations (see Table 7 and Table 8).

Table 7. Comparison of 2nd layer fuzzy weights between company A and college T (Product aspect)

Aspect Major criteria	Center of gravity of fuzzy weights (company A)	Center of gravity of fuzzy weights (college T)	Rank (company A)	Rank (college T)
Product				
Functionality	0.23308	0.27185	1	1
Reliability	0.20265	0.12639	2	5
Usability	0.07473	0.22789	6	2
Efficiency	0.19313	0.08797	4	6
Maintainability	0.19407	0.19448	3	3
Portability	0.13995	0.13001	5	4

Table 8. Comparison of 2nd layer fuzzy weights between company A and college T (Management aspect)

Aspect Major criteria	Center of gravity of fuzzy weights (company A)	Center of gravity of fuzzy weights (college T)	Rank (company A)	Rank (college T)
Management				
Vender	0.20512	0.27557	3	2
Cost	0.41179	0.57178	1	1
Implementing time	0.39963	0.16653	2	3

3rd layer Comparison of the Hierarchy

As presented in Table 9 as below, four cost issues including software cost, hardware cost, annual maintenance fee and staff training fee are all ranked within top 10 important criteria to both industries. But time related criteria containing time behavior, planning & preparation time, BPR & system tuning time and testing & go-live time in semiconductor industry are more important than in education industry, it might reflect the business process pace in different industries.

Table 9. Comparison of entire 32 criteria's fuzzy weights between company A and college T

Aspect Major criteria Sub criteria	Center of gravity of fuzzy weights (company A)	Center of gravity of fuzzy weights (college T)	Rank (company A)	Rank (college T)
Product				
Functionality				
Suitability	0.02302	0.03078	17	13
Accuracy	0.02472	0.02826	16	15
Interoperability	0.01410	0.02076	26	22
Compliance	0.01272	0.01809	28	28
Security	0.01803	0.02570	21	17
Reliability				
Maturity	0.01520	0.01894	23	26

Fault tolerance	0.02891	0.01852	14	27
Recoverability	0.03474	0.02127	11	21
Usability				
Understandability	0.00608	0.03445	32	11
Learnability	0.01399	0.04066	27	9
Operability	0.01170	0.02775	29	16
Efficiency				
Time behavior	0.04201	0.01500	9	29
Resource behavior	0.03420	0.02487	12	18
Maintainability				
Analyzability	0.02238	0.02310	18	20
Changeability	0.02081	0.01907	19	25
Stability	0.01457	0.02848	25	14
Testability	0.01940	0.01950	20	24
Portability				
Adaptability	0.01726	0.01369	22	31
Installability	0.01168	0.01967	30	23
Conformance	0.01116	0.01313	31	32
Replaceability	0.01484	0.01425	24	30
Management				
Vender				
Market share & reputation	0.02619	0.02476	15	19
Industrial credential	0.04655	0.05772	8	6
Service & support	0.04180	0.06063	10	5
Training solution	0.03400	0.04824	13	7
Cost				
Software cost	0.06107	0.08616	7	2
Hardware cost	0.07546	0.08472	5	3
Annual maintenance	0.08115	0.14504	2	1
Staff training	0.07791	0.06510	4	4
Implementing time				
Planning & preparation	0.06349	0.03721	6	10
BPR & system tuning	0.07834	0.03242	3	12
Testing & go-live	0.14646	0.04272	1	8

5. Conclusion

This study proposes a stepwise systematic model for group decision makers to select an appropriate ERP system effectively and efficiently. The model introduces ISO 9126 software quality model to interpret the product characteristics of ERP system, hence, a more specialized overall model is conducted for ERP selection problem. Fuzzy AHP method is also applying to evaluate the ERP system alternatives of a real-world MCDM problem.

According to the two successful cases in various industries, our proposed model is practical and flexible for use. Among the cases study, there are 32 criteria sifted out from two aspects, product aspect and management aspect, respectively. Based on the comparison between semiconductor industry of company A and education industry of college T, we found that various industries exist diverse weight priorities between criteria of product aspect. For example, the reliability of ERP system is vital to semiconductor industry against education industry. Nevertheless, we also discovered that although implementing time is most important in semiconductor industry, the cost issue is significantly important in both various industries.

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