

Research on Stage Index Construction and Fuzzy Comprehensive Evaluation on Enterprise Informatization

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Abstract: This study presents an application of the AHP in the performance evaluation of information system by developing a fuzzy comprehensive evaluation model and a grey clustering method. Its aim is to propose a dynamic analytical framework on enterprise informatization evaluation based on the stage characteristics of implementation. Firstly, it summarizes and compares the existing literatures on informatization evaluation. Secondly, it focuses on the stage characteristics of enterprise informatization's implementation. Thirdly, it proposes an evaluation framework consisting of five elements and indices system aiming at three stages of enterprise informatization. Finally, a case study is illustrated the application of the evaluation model and the evaluation process.

Keywords: Analytic hierarchy process, enterprise informatization, fuzzy comprehensive evaluation, stage model

INTRODUCTION

In the age of global economy, fierce competition and rapid development of information technology, the information has become a lifeline and core competitive force. Two basic points of view can be used for understanding its role: the acquisition of a competitive advantage at the value chain and the creation and enhancement of core competencies (Duhan *et al.*, 2001; Laurindo, 2009). Enterprise informatization refers to the process of applying the information network technology, computer, internet and E-business to the market research, product development, technical reform, quality control, supply chain, cash flow and product distribution for realizing the informatization (Abereijo *et al.*, 2009; Chuang *et al.*, 2009).

The thing that matters is not whether to implement informatization or not, but whether to improve the operation efficiency and effectiveness or not (Pinheiro, 2010). The evaluation of enterprise informatization is significant because the process can help us find the system defects.

The studies about evaluation of enterprise informatization focus on the three issues: one is involved in the forecasting and evaluation on the economical benefit of information system, one is related to the quality of information system and the others pay more attention to the multi-index comprehensive evaluation of information system. By summarizing and comparing the recent correlative studies, we find that the literature about the evaluation on efficiency and effectiveness of enterprise informatization is seldom. The reason lies in the fact that the investment in enterprise informatization is obvious and numerable, but the output and benefit of the item is complicated and not easy to evaluate. Just as

Robert Solow said, "You see computers everywhere but in the productivity statistics because computers are not as productive as you think" (Solow, 1987). "Information systems planning in an uncertain environment" (Dinesh *et al.*, 2012).

This study is aiming to establish a dynamic analytical framework on enterprise informatization evaluation based on the stage characteristics of implementation. A fuzzy comprehensive evaluation method has been set out in this study and has proven to be especially useful. The application of the analytic hierarchy process to the field of informatization system performance evaluation is an advance with respect to previous studies on the application of multi-criteria methods in which only quantitative variables have been used.

STAGE DEVELOPMENT OF ENTERPRISES INFORMATIZATION

"Stages of growth" models have been used widely in both organizational research and information systems research. The stage characteristics hypothesis was first proposed by Nolan (1973), who suggested that the growth of computing follows an S-shaped curve that can be divided into four stages: initiation, contagion, control and integration. Subsequently, Nolan added another two stages, data administration and maturity, thereby creating a six-stage model (Nolan, 1973). King and Teo (1997) propose and empirically validate a stage of growth model for the evolution of information Systems Planning (ISP). Xu and Quaddus (2005) present a six-stage model of the KMS diffusion process, specifically to identify the sequence of stages of the process.

In general, the earlier application of the information technology in enterprise management is tactical level. With its extend to other fields, the influence of information technology in enterprise management will be strategic, which will be go from the automation tools and the communication means, decision support, to the change of organization structure and business model. The process of enterprise informatization's implementation leads to the stage characteristics of informatization level (Zhiping and Jinyu, 2012).

In space, the application of information technology is gradually from the department scope, the inter-department scope to the outside organization, which connects the enterprises with the environment. With the broad application, information technology breaks the horizontal limit, vertical limit and external limit, which facilitate the sharing and transfer between the inside with the outside of the organization. In epistemology, people's understand to the application of information technology is based on the long-term practice, which is a successive and developing process. So, the level of informatization does not depended on how long it progress, but how people know about it. The understandings for the informatization and the actuality

of enterprises have an important influence on the effect of the application of information technology. The stage characteristics of informatization implementation have an important influence on the construction of index system.

AN EVALUATION FRAMEWORK FOR ENTERPRISES INFORMATIZATION

In general, evaluation system consists of five elements: evaluation objectives, evaluation principle, evaluation index, evaluation criteria and evaluation methods. As evaluation index is involved in the evaluation items, it is an important part. As Fig. 1, this study establishes an evaluation framework for enterprise informatization based on informatization level and stages. The evaluation process is as followed.

Appraise the alignment between information planning and enterprise strategy: Today many companies make large investments in Information Systems (IS). Yet executives often question the business-IS alignment, namely whether these investments support their strategic objectives or whether opportunities to exploit IS for competitive advantage are being over looked (Henderson and

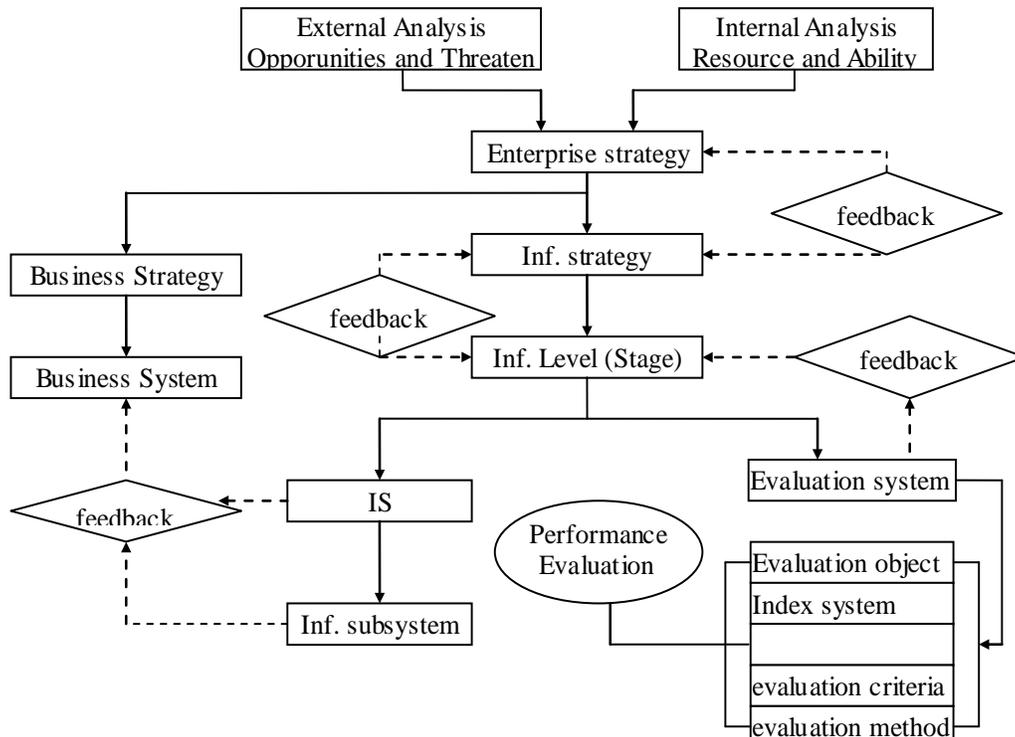


Fig. 1: Evaluation framework for enterprise informatization

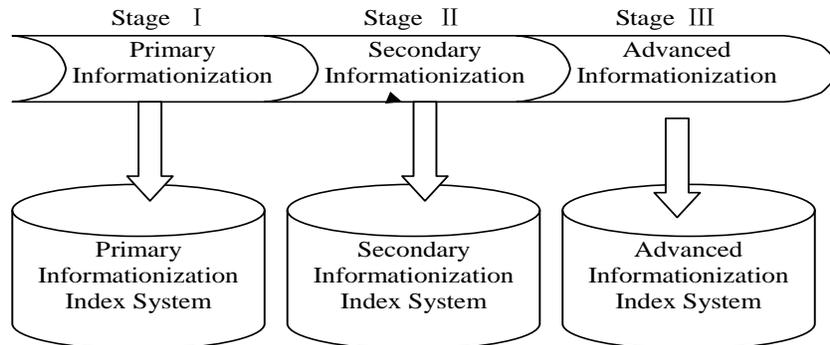


Fig. 2: Index system based on stage evolution of enterprise informatization

Venkatraman, 1993). It is necessary to appraise the alignment between IS planning and enterprise general strategy (Grover and Rajiv, 2007). The integration of enterprise strategy and IS planning is helpful to improve the alignment, which will make a support in goal-orientation, resource allocation, organization design and projects implement.

Appraise the present informatization level (stage): Owing to the stage characteristics, there is one area considered important for the right evaluation is the present informatization level (stage). This study divides the evolution of informatization into three stages: primary informatization, secondary informatization and advanced informatization.

- **Primary stage informatization:** Primary informatization refers to the low-level application of information technology in production, operation and management. Enterprise gradually applies and fit CAD/CAM, PLC, DCS, OA/MIS, MIS, OA and CAPP. Enterprises establish the data-base, which supply the decision-making with information. The enterprise is still not familiar with information system and the attention to the economic performance of information system is lacking.
- **Secondary stage informatization:** Secondary informatization refers to the high-level application of information technology in production, operation and management. Managers pay more attention to the significance of information management and cost control. Enterprises gradually apply and fit CNC, FMS, PDM, APC and the application of some IT (such as: CAD, CNC, FMS, DCS, FC) is familiar. Enterprise basically accomplishes the function of MRP/II, ERP, SCM, CRM and DSS. Enterprises establish the data-base and carry out data mining, which supply the decision-making support for managers. The ICT (such as: data base and telecommunication) is used to collect, process, memory and transmit the data about production,

distribution, financing, human resource and so on in the enterprise, which connect the “information island” together.

- **Advanced stage informatization:** Advanced informatization refers to the top-level application of information technology in production, operation and management. The application of information system is from the single function to integrative function. The enterprise accomplishes the high integration of control and management by the application of CIMS、CIPS, enterprise integration and etc. The enterprise accomplishes the high information of business service by the application of B2B, B2C and E-business. Zero Inventories is achieved by internet marketing and payment, supply chain management system. The enterprise begins to examine and evaluate the various costs and benefits of IS, analyze and solve the problem about the investment in IS in all round.

As the Fig. 2, the above three stage model for the evolution of information systems is used to analyze and estimate the present level and development stage, which is helpful for the next evaluation project.

Performance evaluation: Performance evaluation is involved in the selection of index system, evaluation methods, economic income and non-economic benefit. Time value, inflation and uncertain factors should be considered in the course of evaluation. This study next proposes the different index system aiming to the different stages of enterprise informatization.

Small and medium enterprises can apply simple method and select the important indices. As for the enterprise in primary informatization stage, it can begin with single business and section to appraise the direct financial performance owing to the low-level and small range in information. As for the enterprise in secondary informatization stage, it need to choice the indirect index step by step. As for the enterprise in advanced

informatization stage, it focuses on the integrated index and long-term performance of information system.

In evaluation methods, the performance evaluation of information system is involved in multifactor (both quantitative and qualitative variables, economic and non-economic variables). In fact, some mature methods are used, including: experts grading method, economic model method, operations research methods, fuzzy comprehensive method, statistical analysis method, neural network method and etc.

Information feedback: According to close loop system theory, as for an effectual evaluation system, a set of effective and timely feedback mechanism is necessary and helpful to adjust and perfect the information strategy (or enterprise strategies). Furthermore, the appraisal of evaluation methods, evaluation index and evaluation process is indispensable. The evaluation system is able to perfect by establishing a dynamic mechanism including organization learning, organization experience accumulation and knowledge management.

THREE STAGE INDEX SYSTEM DESIGNING

Because informatization is involved in various process of enterprise management, the effect is directly and indirectly reflected the value-added point of enterprise management. When the evaluation index system of information system is established, the key operation process should be emphasized.

The index system of primary stage informatization:

In primary stage, the investment of informatization is focused on the core value section, such as: CAD/CAM. In the course of evaluation, related index should be carefully selected on the basis of the different stage of informatization. The index system of primary informatization refers to the Table 1.

The index system of secondary stage informatization:

In secondary stage, the investment of informatization is focused on system integration and information sharing. In the course of evaluation, the indirect indices should be added and selected to reflect

Table 1: Index system of stage evaluation on enterprise informatization

Goal layer	First index layer	Second index layer	Referenced indices
Performance of Enterprise informatization (U)	Stage I : Primary Stage (U ₁)	Production Index (u ₁₁)	Production capacity index; production quality index; production cost index; manufacturing cycle index; work-in-process turnover index
		Logistics Index (u ₁₂)	Days sales of inventory index; in-transit stock index; transportation expenses index; procurement lead time;
		Marketing Index (u ₁₃)	Market shares index; marketing costs index; consumer repurchase; market growth rate
		R&D Index (u ₁₄)	R&D investment index; new production sales ratio; R&D management cost index
	Stage II : Secondary Stage (U ₂)	Finance Index (u ₁₅)	Budget management index; process control index; expense index; profitability index
		Section Index (u ₂₁)	Above indices
		Economical Index (u ₂₂)	Production cost index; design cost index; marketing cost index; financial cost index; management cost index
	Stage III: Advanced Stage (U ₃)	Efficiency Index (u ₂₃)	Production efficiency index; R&d efficiency index; sale rise ratio; finance management level
		Financial Index (u ₃₁)	liquidity index; asset management index; debt-paying index; profitability index
		Logistic and technical Index (u ₃₂)	Quality index; logistic cost index; technical Index; responsiveness index
		User-oriented Index (u ₃₃)	User satisfaction index; market shares index; customer loyalty and profit per customer; consumer repurchase index
		Learning and growing Index(u ₃₄)	HR exploitation index; management innovation index; enterprise growing index

Table 2: Scale of Preference between two elements

Preference weight of importance	Definition	Explanation
1	Equally important	Two activities contribute equally to the objective Experience and judgment slightly favor one
3	Moderately important	Activity over another Experience and judgment strongly or essentially favor one activity over another
5	Strongly important	An activity is strongly favored over another and its dominance demonstrated in practice
7	Very strongly important	The evidence favoring one activity over another is of the highest degree possible of affirmation
9	Extremely important	
2,4,6,8	Intermediates values	Used to represent compromise between the preference listed above
Reciprocals	Reciprocals for inverse comparison	

the effect of information system. The index system also refers to Table 1.

The index system of advanced stage informatization: In advanced stage, the investment of information system is focused on the comprehensive development of IS and integrated management of data and information. In the course of evaluation, the integrated indices should be emphasized on the basis of the above indices, including: financial index, logistic/technical index, user-oriented index and learning/ growing index.

**FUZZY COMPREHENSIVE EVALUATION
PROCESS OF ENTERPRISE
INFORMATIZATION**

Index system: As shown in Table 1, this study constructs the evaluation index system. There are three layers and twelve evaluating indices in the system. The system performance of enterprise informatization (U) is the goal layer; the second index layer consists of three indices: primary stage index (U₁), secondary stage index (U₂) and advanced stage index (U₃); the third index layer is the overall segments of the index layer, including all the u_{ij}.

Given the factors set of system performance of enterprise informatization which will be evaluated is U. Based on different attributes of the factors, U is divided into u₁, u₂..., u_m, namely, there are m subsets. The evaluation comprises three categories and 12 factors.

U = {U₁ (primary stage index), U₂ (secondary stage index), U₃ (advanced stage index)} = {u₁₁, u₁₂, ..., u₃₄}.

The weight for evaluation factors:

$$A = \{A_1, A_2, A_3\} = \{a_{11}, a_{12}, a_{34}\}$$

The weight is calculated by using fuzzy relation equation and method of weight mean. The procedure can be summarized as:

$$A = \begin{bmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \dots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \dots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \dots & \frac{w_n}{w_n} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix}$$

Establish priorities among the elements of the hierarchy by making a series of judgments based on pair wise comparisons of the elements.

where,

- A = Comparison pair wise matrix
- w₁ = The weight of element 1
- w₂ = The weight of element 2
- w_m = The weight of element m

Table 3: Random indices

N	3	4	5	6	7	8	9	10
RI	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

where, a_{ij} are pairwise comparisons from alternatives/criteria given by the decision maker on a verbal scale of nine levels (Table 2).

Check the consistency of the judgments. Consistency Index (CI) is calculated as:

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

where,

- n : dimension of the matrix
- λ_{max} : maximal eigenvalue

Generally, if CR is less than 0.1, the judgments are consistent, so the derived weights can be used. The formulation of CR is:

$$CR = \frac{CI}{RI}$$

where,

- CR : Consistency Ratio,
- RI : Random Index (Table 3)

Saaty (1980) calculated the following random indices: Come to a final decision based on the results of this process.

Confirming the degree of subjection of index: When system performance of enterprise informatization is evaluated, it must be evaluated together by experts, decision-makers and entrepreneurs based on the comment set. The result is the degree of subjection shown as matrix RB_i:

RB = (r_{ij})_{3x5}, RB₁ = (r_{ij})_{5x5}, RB₂ = (r_{ij})_{3x5}, RB₃ = (r_{ij})_{4x5}, r_{ij} = d_{ij}/d, d_{ij} is the number of persons who gives j level on the i-th index, d is the number of all the experts.

THE EVALUATION RESULT

V = {V₁(higher), V₂(high), V₃(middle), V₄(low), V₅(lower)}

Result of the second level fuzzy comprehensive evaluation: We can reduce the integrated evaluating vector of ui according to the theory of fuzzy:

$$B_i = A_i \bullet PB_i = \sum_{k=1}^m \left(a_{ij} \bigwedge_{j=1}^{n_i} r_{ij} \right) = (b_{i1}, b_{i2}, \dots, b_{im}) (i = 1, 2, 3, 4)$$

Result of the first level fuzzy comprehensive evaluation: The fuzzy evaluating matrix of U is R*:

$$R^* = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{bmatrix} = \begin{bmatrix} b_{11} & b_{21} & \dots & b_{1m} \\ b_{21} & b_{22} & \dots & b_{2m} \\ b_{31} & b_{32} & \dots & b_{3m} \\ b_{41} & b_{42} & \dots & b_{4m} \end{bmatrix}$$

Every u_i as one part of U , it reflects some attributes of U . We can distribute the weight according to their essentiality, namely, $A^* = (a_1, a_2, a_3)$. So we can get the integrated evaluating vector: $B^* = A^* \cdot R^* = (b_1, b_2, \dots, b_m)$.

According to the principle of degree of maximum membership degree, given $B_k = \max (b_1, b_2, \dots, b_m)$, the integrated evaluation vector is B_k .

APPLICATION EXAMPLE

With the mathematical model and methods mentioned above, we evaluate the information system performance of one case enterprise. According to the index system, we use the above evaluation model and evaluation method.

Subjection degree of index: The expert group is made up of 20 experts. The group evaluates every index in term of comment set, hence we can get RB_i :

$$RB_1 = \begin{bmatrix} 0.20 & 0.35 & 0.25 & 0.10 & 0.00 \\ 0.25 & 0.30 & 0.30 & 0.15 & 0.00 \\ 0.15 & 0.25 & 0.35 & 0.15 & 0.10 \\ 0.30 & 0.25 & 0.15 & 0.20 & 0.10 \\ 0.20 & 0.35 & 0.25 & 0.15 & 0.15 \end{bmatrix}$$

$$RB_2 = \begin{bmatrix} 0.15 & 0.30 & 0.35 & 0.20 & 0.00 \\ 0.30 & 0.35 & 0.20 & 0.10 & 0.05 \\ 0.25 & 0.20 & 0.30 & 0.15 & 0.10 \end{bmatrix}$$

$$RB_3 = \begin{bmatrix} 0.35 & 0.25 & 0.25 & 0.15 & 0.00 \\ 0.20 & 0.35 & 0.25 & 0.20 & 0.00 \\ 0.15 & 0.25 & 0.35 & 0.15 & 0.10 \\ 0.20 & 0.20 & 0.35 & 0.20 & 0.05 \end{bmatrix}$$

Index weight: The domain experts confirmed the index weight. We have verified the consistency of judging matrix. The consistency is eligible, we receive integrated judging matrix and calculate the weights.

Next, we give the fuzzy comparison matrixes of the criteria level and sub-criteria level. For instance, Table 4 shows the original fuzzy pair-wise comparison matrixes for enterprise informatization evaluation.

$\lambda_{\max} = 3.05$, $CI = 0.025$, $RI = 0.58$, $CR = 0.04 < 0.1$ OK.

Table 4: Pair-wise comparison matrix for the three stage informatization performance

	U ₁	U ₂	U ₃	Priority vector
U ₁	1	3	5	0.11
U ₂	1/3	1	4	0.31
U ₃	1/5	1/4	1	0.58

$$A^* = (0.11 \ 0.31 \ 0.58)$$

As the same way, we can get:

$$A_1^* = (0.32, 0.09, 0.15, 0.07, 0.37)$$

$$A_2^* = (0.31, 0.26, 0.43)$$

$$A_3^* = (0.42, 0.29, 0.13, 0.16)$$

Fuzzy evaluation:

$$R^* = \begin{bmatrix} A_1^* \cdot RB_1 \\ A_2^* \cdot RB_2 \\ A_3^* \cdot RB_3 \end{bmatrix} = \begin{bmatrix} 0.20 & 0.32 & 0.26 & 0.14 & 0.08 \\ 0.23 & 0.27 & 0.29 & 0.15 & 0.06 \\ 0.25 & 0.28 & 0.28 & 0.17 & 0.02 \end{bmatrix}$$

$$B^* = A^* \cdot R^* = A^* \times R$$

$$B^* = [0.11 \ 0.31 \ 0.58] \times \begin{bmatrix} 0.20 & 0.32 & 0.26 & 0.14 & 0.08 \\ 0.23 & 0.27 & 0.29 & 0.15 & 0.06 \\ 0.25 & 0.28 & 0.28 & 0.17 & 0.02 \end{bmatrix}$$

$$B^* = (0.26, 0.28, 0.25, 0.16, 0.05) = 0.28 = V_2$$

$$B_k = \max (0.26, 0.28, 0.25, 0.16, 0.05) = 0.28 = V_2$$

RESULTS AND CONCLUSION

According to the principle of maximum membership degree, the evaluating level of the system performance of enterprise informatization is V_2 , namely, high.

Evaluating the performance of enterprise informatization is an important part for the improvement of enterprise information system. This study emphasizes the periodic characteristics of enterprise informatization's implementation. The process of enterprise informatization's implementation leads to the stage characteristics of informatization level. The evolution of information system can be divided into three stages: the primary informatization, the secondary informatization and the advanced informatization. Aiming at three stages of informatization's implementation, it proposes evaluation framework for enterprise informatization and construct the indexes system. We evaluate the system performance of enterprise informatization by using the three level comprehensive evaluation of fuzzy mathematics. A multicriteria methodology, namely

AHP, has been set out in this study and has proven to be especially useful.

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