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On performance evaluation of ERP systems with fuzzy mathematics

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ABSTRACT

An enterprise resource planning (ERP) system is a complex network composed of various business processes. This paper proposes a method based on stochastic-flow network model to evaluate the performance of an ERP system depending upon the fuzzy linguistic results of the ERP examination of the users involved. The nodes in the network denote the persons responsible for the business tasks during the processes. The arcs between nodes denote the process precedence relationships in the ERP system. When the process starts, the documents are initiated from the source node to its succeeding nodes. Finally, the documents are released in the destination node. Thus, the performance of an ERP system is related to the document flow under the network. The failure of an ERP system is therefore described as in the condition that the flow of the system is under the acceptable level *d*. By using the fuzzy linguistic results of the ERP examination of the users, we propose a fuzzy linguistic performance index, defuzzified from the probability of maximal flow not less than *d*, to evaluate the performance of an ERP system. An algorithm is subsequently proposed to generate the performance index, which can be used to assess the system performance either before or after the system going live.

1. Introduction

In decades, adopting an enterprise resource planning (ERP) system has been a promised way for corporation to gain competition advantages in the world (Jones & Young, 2006; Sebastianelli & Rishel, 2003; Tsai, Fan, Leu, Chou, & Yang, 2007). Many researchers have contributed methods to evaluate the performance of ERP systems. These researches can be viewed as two general parts in development. One part is to investigate the financial performance when corporation invested an ERP system. For example, Wu et al. (2007) proposed a method to quantify the tangible and intangible performance of an ERP system. The tangible aspect was analyzed by Hochstrasser model, and the intangible one was quantified by fuzzy evaluation approach which combined nine value drives in corporation value creation processes. Another part, the majority researches, are on the manipulations of critical factors/items that can be obtained from various ways. The first way is by literature review, such as the work of Dowlatshahi (2005) who surveyed current ERP literatures and identified the four ERP strategic factors (cost of ERP implementation, implementation time and return on investment issues, ERP employee training, and effective use of ERP features/applications), and the work of Al-Mashari et al. (2003) who concluded a taxonomy of the critical success key factors (SKF) involving technical and organizational imperatives. The second way is from questionnaire, such as those done by Lin et al. (2004) who used the data envelopment analysis approach to evaluate the relationship between ERP continuous investment and technical efficiency. They also utilized the Tobit regression to investigate the relationship between efficiency scores and the ERP continuous investment based on the concept of total cost ownership. The third way are from heuristics such as the work of Chand et al. (2005) who provided a balanced-scorecard based framework for valuing the strategic performance of an ERP system, the work of Yang et al. (2007) who presented a performance evaluation model of ERP implementation utilizing fuzzy measures, the work of Chang et al. (2007) who constructed a conceptual model to evaluate the performance and competitive advantages associated with ERP from a supply chain management perspective, and the work of Lin et al. (2006) who proposed a statistical method based on Parasuraman and a revised performance evaluation matrix to set up a standard performance upper and lower control limits in terms of Taguchi method and Shewhart control charts.

Although the above methods for evaluating the performance of ERP systems were developed, they seldom put emphasis on how much can the familiarity of user training about the ERP system influence the performance of the underlined system, especially, when the results of user training test are appeared to be of linguistic grades instead of exact scores. To fill this gap, we proposes an analytical approach combining the flow network model and

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fuzzy set theory to generate a fuzzy linguistic performance index to assess the performance of an ERP system depending upon the linguistic results of the certification/examination of the users involved.

A stochastic-flow network (Lin, 2007b) is a network in which arcs as well as nodes all have several states/capacities and may fail. This kind of network is often used to model many real-world applications such as project management (Lin, 2007c), information systems (Lin, 2007b), and multi-commodity applications (Lin, 2007a, 2007d). An ERP system is a complicated process system, which can be viewed as a complex network composed of various business processes. We apply the stochastic-flow network to model an ERP system. The nodes in the network denote the persons responsible for the business operations in the processes. The arcs between nodes denote the process precedence relationships configured at the installation stage of the ERP system. When the process starts, the documents are initiated from the source node to its succeeding nodes. Finally, the documents end in the destination node. Thus, the performance of an ERP system is related to the document flow under the network. The failure of an ERP system is therefore described as in the condition that the system's flow is under the acceptable level d. Here, we propose a linguistic performance index $\widetilde{R}_d$, based on the probability R_d that the maximal flow is not less than d, to evaluate the performance of an ERP system.

Lin (2007b) had proposed an algorithm based on minimum paths (MPs) to calculate R_d for a stochastic-flow network. A MP is a sequence of nodes and arcs from source s to sink t without cycles. Based on Lin's algorithm, the probability R_d for an ERP system is achieved under the condition that the probability of a node's capacity can be previously defined. After that, a linguistic performance index $\widetilde{R}_d$ is defuzzified from R_d. To address the capacity of a node, it is said that a low capacity node can typically be assessed by the lack of right knowledge about the operations of the underlined system. Some researches had revealed the fact that the knowledge of company users concerning ERP operations is an important SKF in the ERP systems (Amoako-Gyampah & Salam, 2004; Dowlatshahi, 2005; Yu, 2005). To validate the ERP knowledge captured by the users, an objective examination/certification is valuable. Generally, the results of the test are given into grades such as "excellent", "good", "normal", "bad" and "failed" instead of the exact scores. These linguistic grades can be advantageously handled by the fuzzy set theory (Kosko, 1997; Wang, 2005). The remainder of the work is described as follows: The assumption for the model discussed here is presented in Section 2. The network model for an ERP system complied with the assumption is discussed in Section 3. A procedure to evaluate $\widetilde{R}_d$ is proposed subsequently in Section 4. Then, the calculation of the linguistic performance index is illustrated by some numerical examples in Section 5.

2. Assumptions

Let $G = (A,N,M)$ be a stochastic-flow network for an ERP system where $A = \{a_i|1 \leqslant i \leqslant n\}$ is the set of arcs, $N = \{b_i|1 \leqslant i \leqslant p\}$ is the set of nodes, and $M = (m_1,m_2,\ldots,m_p)$ is a vector with m_i (an integer) being the maximal capacity of node b_i. Such a G is assumed to satisfy the following assumptions:

(1) The capacity of each node b_i is an integer-valued random variable which takes values from the set $\{0,1,2,\ldots,m_i\}$ according to a given distribution governed by μ_i, where μ_i is a membership function mapping from fuzzy set {excellent, good, normal, bad, failed} to $[0,1]$.
(2) The arcs are perfect and unlimited in capacity under the ERP environment.
(3) Flow in G must satisfy the flow-conservation law (Ford & Fulkerson, 1962).
(4) The nodes are statistically independent from each other.

Table 1
Two grades among five of μ_1 membership function for node b_1

Capacities of node b_1	Two example grades in the ERP test	
	Good	Bad
0	$\mu_1(good)(0) = 0.002$	$\mu_1(bad)(0) = 0.23$
1	$\mu_1(good)(1) = 0.003$	$\mu_1(bad)(1) = 0.60$
2	$\mu_1(good)(2) = 0.005$	$\mu_1(bad)(2) = 0.10$
3	$\mu_1(good)(3) = 0.01$	$\mu_1(bad)(3) = 0.012$
4	$\mu_1(good)(4) = 0.13$	$\mu_1(bad)(4) = 0.0555$
5	$\mu_1(good)(5) = 0.65$[a]	$\mu_1(bad)(5) = 0.0025$
6	$\mu_1(good)(6) = 0.20$	$\mu_1(bad)(6) = 0.0$

[a] $\Pr\{X|X \geqslant 5$, if b_1 is in good grade$\} > \Pr\{X|X \geqslant 5$, if b_1 is in bad grade$\}$.

The capacity of a node means the throughput of a node to successfully process the documents. Since the different node represents different person in the process, the respective probability distribution is also different from each other. The probability is governed by μ_i membership function. For a certain condition, one can adopt the same set of membership functions for all persons to fit in this approach. Table 1 shows two grades among five of μ_1 membership function for node b_1. If node b_1 gets a "bad" grade in the ERP examination, the membership degree (probability) of capacity 5 for node b_1 is $\mu_1(bad)(5) = 0.0025$, and if he gets a "good" grade in the examination, the probability of capacity 5 for node b_1 is $\mu_1(good)(5) = 0.65$. This means that the probability of the capacity greater or equal to 5 for the person being good in the test is larger than that for the person being bad in the test.

3. The ERP network model

In the context of an ERP environment, a process starts can initiate several document flow from the source node s through a set of alternative paths depending on the business considerations without loop (i.e. through MPs) to the destination node t in order to complete the business process. Suppose $P_1,P_2,\ldots,P_z$ are totally the MPs from s to t. Thus, the ERP network model can be described in terms of two vectors: the capacity vector $X = (x_1,x_2,\ldots,x_p)$ and the flow vector $F = (f_1,f_2,\ldots,f_z)$ where x_i denotes the current capacity of node b_i and f_j denotes the current flow on P_j. Then such a vector F is feasible if and only if

$$\sum_{j=1}^{z}\{f_j|b_i \in P_j\} \leqslant m_i \quad \text{for each } i = 1,2,\ldots,p. \tag{1}$$

Eq. (1) describes that the total flow through b_i can not exceed the maximal capacity of b_i. We denote such set of F as $U_M \equiv \{F|F$ is feasible under $M\}$. Similarly, F is feasible under $X = (x_1,x_2,\ldots,x_p)$ if and only if

$$\sum_{j=1}^{z}\{f_j|b_i \in P_j\} \leqslant x_i \quad \text{for each } i = 1,2,\ldots,p. \tag{2}$$

For clarity, let $U_X \equiv \{F|F$ is feasible under $X\}$. The maximal flow under X is defined as $V(X) \equiv \max\{\sum_{j=1}^{z} f_j|F \in U_X\}$.

3.1. System performance evaluation

Given the level d (the required document flow), the system reliability R_d is the probability that the maximal flow is not less than d, i.e., $R_d \equiv \Pr\{X|V(X) \geqslant d\}$. To calculate R_d, it is advantageously to find the minimal capacity vector in the set $\{X|V(X) \geqslant d\}$. A minimal