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AN EVALUATION METHOD FOR ENTERPRISE RESOURCE PLANNING SYSTEMS

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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 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 flow of the documents through 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. We propose a performance index, the probability of the 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.

Keywords: Reliability, enterprise resource planning system, stochastic-flow network, minimal path, performance index

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 [7, 14, 15]. 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. [16] 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 [5] 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. [1] 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. [8] 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. [3] who provided a balanced-scorecard based framework for valuing the strategic performance of an ERP system, the work of Yang et al. [18] who presented a performance-evaluation model of ERP implementation utilizing fuzzy measures, the work of Chang et al. [4] 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. [9] 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. To fill the gap, this paper proposes an analytical approach based on the flow network model to assess the performance of an ERP system depending upon the results of the certification examination of the user involved.

A stochastic-flow network [11] 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 [12], information systems [11], and multi-commodity applications [10, 13]. 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 which are the outputs of the task on the node 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 through the network. The failure of an ERP system is therefore described as in the condition that the system's flow (i.e., the document flow) is under the acceptable level d. Here, we propose a performance index R_d, the probability that the maximal document flow is not less than d, to evaluate the performance of an ERP system. Since the capacity of a node (i.e., the node's throughput) depends on the familiarity of person's training about the underlined process, it is stochastic in nature. Therefore, the ERP system can be treated as a stochastic-flow network.

Lin [11] 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 performance index R_d for an ERP system is achieved under the condition that the probability of a node's capacity can be previously defined. 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 [2, 5, 19]. To validate the ERP knowledge captured by the users, an objective examination/certification is valuable. 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. An algorithm to evaluate R_d is proposed subsequently in Section 4. Then, the calculation of the system performance R_d is conducted by some numerical examples in Section 5.

2. Assumptions

Let $G = (A, N, M)$ be a stochastic-flow network for an ERP system where $A = \{a_i | 1 \leq i \leq n\}$ is the set of arcs, $N = \{b_i | 1 \leq i \leq p\}$ 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 D_i, where D_i is a mapping from $\{0, 1\}$ to the probability distributions of the node's capacity. The state '0' denotes the result of the ERP examination for the user being failed, and '1' denotes the result of the ERP examination for the user being successful (i.e., passed).
2. The arcs are perfect and unlimited in capacity under the ERP environment.
3. Flow in G must satisfy the flow-conservation law [6].
4. The nodes are statistically independent from each other.

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. This probability is governed by D_i function. Table 1 shows an example of the usage of D_1 function for node b_1. If node b_1 failed in the ERP examination (for example, the ERP certification tests provided by SAP Co.) , the probability of capacity 5 for node b_1 is $D_1(0)(5) = 0.0025$, and if it is successful in the examination, the probability of capacity 5 for node b_1 is $D_1(1)(5) = 0.65$. This means that the probability of the capacity greater or equal to 5 for the person passed the test is larger than that for the person failed the test.

Table 1: The usage of D_1 function for node b_1

	Prob. for the results of ERP examination	
Capacities of node b_1	passed	failed
0	$D_1(1)(0) = 0.002$	$D_1(0)(0) = 0.23$
1	$D_1(1)(1) = 0.003$	$D_1(0)(1) = 0.60$
2	$D_1(1)(2) = 0.005$	$D_1(0)(2) = 0.10$
3	$D_1(1)(3) = 0.01$	$D_1(0)(3) = 0.055$
4	$D_1(1)(4) = 0.13$	$D_1(0)(4) = 0.012$
5	$D_1(1)(5) = 0.65^*$	$D_1(0)(5) = 0.003$
6	$D_1(1)(6) = 0.20$	$D_1(0)(6) = 0.0$

* $\Pr\{X|X \geq 5$, if b_1 is passed$\} > \Pr\{X|X \geq 5$, if b_1 is failed$\}$

3. The ERP Network Model

In the context of an ERP environment, a process start 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

$$\sum_{j=1}^{z}\{f_j|b_i \in P_j\} \le m_i \quad \text{for each } i = 1, 2, \ldots, p. \tag{3.1}$$

Equation (3.1) describes that the total flow through b_i can not exceed the maximal capacity of b_i. We denote such set of F as $U_M \equiv \{F|F \text{ is feasible under } M\}$. Similarly, F is feasible under $X = (x_1, x_2, \ldots, x_p)$ if and only if

$$\sum_{j=1}^{z}\{f_j|b_i \in P_j\} \le x_i \quad \text{for each } i = 1, 2, \ldots, p. \tag{3.2}$$

Equation (3.2) describes that the total flow through b_i can not exceed the current capacity of b_i. For clarity, let $U_X \equiv \{F|F \text{ is feasible under } X\}$. The maximal flow under X is defined as $V(X) \equiv \max\{\sum_{j=1}^{z} f_j|F \in U_X\}$.

System performance evaluation

Given the level d (the required document flow), the system performance index R_d is the probability that the maximal flow is not less than d, i.e., $R_d \equiv \Pr\{X|V(X) \ge d\}$. To calculate R_d, it is advantageously to find the minimal capacity vector in the set $\{X|V(X) \ge d\}$. A minimal capacity vector X is said to be a lower boundary point for d if and only if (i) $V(X) \ge d$ and (ii) $V(Y) < d$ for any other vector Y such that $Y < X$, in which $Y \le X$ if and only if $y_j \le x_j$ for each $j = 1, 2, \ldots, p$ and $Y < X$ if and only if $Y \le X$ and $y_j < x_j$ for at least one j. Suppose there are totally q lower boundary points for d: $X_1, X_2, \ldots, X_q$, then the performance index R_d is $\Pr\{\bigcup_{i=1}^{q}\{X|X \ge X_i\}\}$.

Generation of all lower boundary points for d

At first, we find the flow vector $F \in U_M$ such that the total flow of F equals d. It is defined as in the following equation.

$$\sum_{j=1}^{z} f_j = d. \tag{3.3}$$

Then, let $\mathbf{F}$=$\{F|F \in U_M$ and satisfies Equation (3.3)$\}$. We show that a lower boundary point X for d is existed if there exists an $F \in \mathbf{F}$ by the following lemma.

Lemma 3.1 *Let X be a lower boundary point for d, then there exists an $F \in \mathbf{F}$ such that*

$$x_i = \sum_{j=1}^{z}\{f_j|b_i \in P_j\} \quad \text{for each } i = 1, 2, \ldots, p. \tag{3.4}$$

Proof. If X is a lower boundary point for d, then there exists an F such that $F \in U_X$ and $F \in \mathbf{F}$. It is known that $\sum_{j=1}^{z}\{f_j|b_i \in P_j\} \le x_i$, $\forall i$. Suppose there exists a k such that $x_k > \sum_{j=1}^{z}\{f_j|b_k \in P_j\}$. Set $Y = (y_1, y_2, \ldots, y_{k-1}, y_k, y_{k+1}, \ldots, y_p) = (x_1, x_2, \ldots, x_{k-1}, x_k - 1, x_{k+1}, \ldots, x_p)$. Hence $Y < X$ and $F \in U_Y$ (since $\sum_{j=1}^{z}\{f_j|b_i \in P_j\} \le y_i$, $\forall i$), which indicates that $V(Y) \ge d$ and contradicts to that X is a lower boundary point for d. Thus $x_i = \sum_{j=1}^{z}\{f_j|b_i \in P_j\}$, $\forall i$□

Given any $F \in \mathbf{F}$, we generate a capacity vector $X_F = (x_1, x_2, \ldots, x_p)$ via Equation (3.4). Then the set $\Omega = \{X_F|F \in \mathbf{F}\}$ is built. Let $\Omega_{min} = \{X|X \text{ is a minimal vector in } \Omega\}$. Lemma 3.1 implies that the set Ω includes all lower boundary points for d. The following lemma further proves that Ω_{min} is the set of lower boundary points for d.

Lemma 3.2 *Ω_{min} is the set of lower boundary points for d.*

Proof. Firstly, suppose $X \in \Omega_{min}$ (note that $V(X) \geq d$) and it is not a lower boundary point for d. Then there exists a lower boundary point Y for d such that $Y < X$, which implies $Y \in \Omega$ and thus contradicts to that $X \in \Omega_{min}$. Hence X is a lower boundary point for d. Conversely, suppose X is a lower boundary point for d (note that $X \in \Omega$) but $X \notin \Omega_{min}$ i.e., there exists a $Y \in \Omega$ such that $Y < X$. Then $V(Y) \geq d$ which contradicts to that X is a lower boundary point for d. Hence $X \in \Omega_{min}$. □

We then propose an algorithm in Section 4 to further filter out all non-minimal ones in Ω to obtain the set Ω_{min}.

4. Algorithm

Same as the approaches in the work of Xue [17] and Lin [10–12], we suppose all MPs have been pre-computed. All lower boundary points for d are generated by Algorithm 1. Step (1) depicts that according to the MPs, the feasible F under Equation (3.1) and (3.3) is enumerated into set $\mathbf{F}$. Then, the candidate vector set Ω for lower boundary points can be derived from $\mathbf{F}$ under Equation (3.4) in step (2). Finally, the set Ω_{min} of lower boundary points is filtered out by comparing with each other from step (3).

Algorithm 1: Find all lower boundary points for d

1. Find all feasible flow vector $F = (f_1, f_2, \ldots, f_z)$ satisfying both capacity and demand constraints.
   (a) **enumerate** f_j for $1 \leq j \leq z,\ 0 \leq f_j \leq m_i$ **do**
   (b) **if** f_j satisfies the following equations
   $\sum_{j=1}^{z}\{f_j|b_i \in p_j\} \leq m_i$ and $\sum_{j=1}^{z} f_j = d$ for $1 \leq i \leq p$
   (c) **then** $\mathbf{F} = \mathbf{F} \cup \{F\}$
   (d) **endif**
   (e) **end enumerate**
2. Generate the set $\Omega = \{X_F|F \in \mathbf{F}\}$.
   (a) **for** F in $\mathbf{F}$ **do**
   (b) $x_i = \sum_{j=1}^{z}\{f_j|b_i \in P_j\}$ for each $i = 1, 2, \ldots, p$.
   (c) $U_X = U_X \cup \{X_F\}$ //where $X_F = (x_1, x_2, \ldots, x_p)$ may have duplicates.
   (d) **endfor**
   (e) **for** X in U_X **do** //Remove the redundant vectors.
   (f) **if** $X \notin \Omega$ **then** $\Omega = \Omega \cup \{X\}$
   (g) **endif**
   (h) **endfor**
3. Find the set $\Omega_{min} = \{X|X$ is a minimal vector in $\Omega\}$. Let $J = \{j|X_j \notin \Omega_{min}\}$.
   (a) **for** $i \notin J$ and $1 \leq i \leq |\Omega|$ **do** //where $|\Omega|$ denotes the number of elements in Ω.
   (b) **for** $j \notin J$ and $i < j \leq |\Omega|$ **do**
   (c) **if** $X_j \leq X_i$ **then** $J = J \cup \{i\}$ and goto (h)
   (d) **else if** $X_j > X_i$ **then** $J = J \cup \{j\}$
   (e) **endif**
   (f) **endfor**
   (g) $\Omega_{min} = \Omega_{min} \cup \{X_i\}$
   (h) **endfor**

5. Numerical Examples

Figure 1 shows an ERP network with one specific process. When process starts, node b_1 will initiate the document flow and send it via either node b_2 or b_3 to node b_4 who ends the process, where b_2 and b_3 are considered to be the alternative persons for optional double check in the process. Table 2 gives the result of a fictitious examination for the four persons at the ERP pre-implementation stage and Table 3 shows the relation between probability distributions and the various capacities of 4 nodes under different results of an ERP examination.

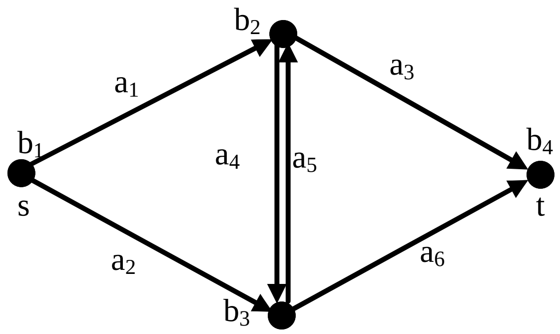

Figure 1: An one-process ERP network

Table 2: The fictitious examination for the four persons

Persons(Nodes)	b_1	b_2	b_3	b_4
Exam.	passed	failed	passed	passed
Prob. Distribution	$D_1(1)$	$D_2(0)$	$D_3(1)$	$D_4(1)$

Table 3: The probability of various capacities for four nodes

	Probabilities for different capacities						
Mapping Functions	0	1	2	3	4	5	6
$D_1(1)$	0.002	0.003	0.005	0.01	0.13	0.65	0.20
$D_1(0)$	0.23	0.60	0.10	0.055	0.012	0.003	0.0
$D_2(1)$	0.001	0.002	0.01	0.02	0.10	0.7	0.167
$D_2(0)$	0.20	0.67	0.11	0.012	0.007	0.001	0.0
$D_3(1)$	0.002	0.003	0.01	0.01	0.10	0.6	0.275
$D_3(0)$	0.30	0.55	0.125	0.012	0.01	0.003	0.0
$D_4(1)$	0.002	0.003	0.01	0.01	0.10	0.7	0.175
$D_4(0)$	0.175	0.50	0.30	0.012	0.01	0.003	0.0

Assume that an acceptable level of the document flow is required to be five documents from b_1 to b_4 (i.e., R_5). All lower boundary points for 5 are generated as in the following calculations. Here, there are 4 MPs existed: $P_1 = \{b_1, b_2, b_4\}$, $P_2 = \{b_1, b_2, b_3, b_4\}$, $P_3 = \{b_1, b_3, b_4\}$, and $P_4 = \{b_1, b_3, b_2, b_4\}$.

1. Find all feasible vector $F = (f_1, f_2, f_3, f_4)$ satisfying both capacity and demand constraints.

   enumerate f_j for $1 \leq j \leq 4,\ 0 \leq f_j \leq 6$ **do**
   if f_j satisfies the following equations
   $f_1 + f_2 + f_3 + f_4 \leq 6$ (for b_1),
   $f_1 + f_2 + f_4 \leq 5$ (for b_2),
   $f_2 + f_3 + f_4 \leq 6$ (for b_3),
   $f_1 + f_2 + f_3 + f_4 \leq 6$ (for b_4) and
   $f_1 + f_2 + f_3 + f_4 = 5$ (for the demand d)
   then $\mathbf{F} = \mathbf{F} \cup \{F\}$
   endif
   end enumerate
   The result of **F** is
   {(0, 0, 0, 5), (0, 0, 1, 4), (0, 0, 2, 3), (0, 0, 3, 2), (0, 0, 4, 1), (0, 0, 5, 0), (0, 1, 0, 4), (0, 1, 1, 3), (0, 1, 2, 2), (0, 1, 3, 1), (0, 1, 4, 0), (0, 2, 0, 3), (0, 2, 1, 2), (0, 2, 2, 1), (0, 2, 3, 0), (0, 3, 0, 2), (0, 3, 1, 1), (0, 3, 2, 0), (0, 4, 0, 1), (0, 4, 1, 0), (0, 5, 0, 0), (1, 0, 0, 4), (1, 0, 1, 3), (1, 0, 2, 2), (1, 0, 3, 1), (1, 0, 4, 0), (1, 1, 0, 3), (1, 1, 1, 2), (1, 1, 2, 1), (1, 1, 3, 0), (1, 2, 0, 2), (1, 2, 1, 1), (1, 2, 2, 0), (1, 3, 0, 1), (1, 3, 1, 0), (1, 4, 0, 0), (2, 0, 0, 3), (2, 0, 1, 2), (2, 0, 2, 1), (2, 0, 3, 0), (2, 1, 0, 2), (2, 1, 1, 1), (2, 1, 2, 0), (2, 2, 0, 1), (2, 2, 1, 0), (2, 3, 0, 0), (3, 0, 0, 2), (3, 0, 1, 1), (3, 0, 2, 0), (3, 1, 0, 1), (3, 1, 1, 0), (3, 2, 0, 0), (4, 0, 0, 1), (4, 0, 1, 0), (4, 1, 0, 0),(5, 0, 0, 0)}.

2. Generate the set $\Omega = \{X_F | F \in \mathbf{F}\}$.

   for F in **F** **do**
   $x_1 = f_1 + f_2 + f_3 + f_4,\ x_2 = f_1 + f_2 + f_4,\ x_3 = f_2 + f_3 + f_4,$
   $x_4 = f_1 + f_2 + f_3 + f_4$
   $U_X = U_X \cup \{X_F\}$ //where $X_F = (x_1, x_2, x_3, x_4)$ may have duplicates.
   endfor
   for X in U_X **do** //Remove the redundant vectors.
   if $X \notin \Omega$ **then** $\Omega = \Omega \cup \{X\}$
   endif
   endfor
   The result of Ω is
   {X_1 =(5, 5, 0, 5), X_2 =(5, 5, 1, 5), X_3 =(5, 4, 1, 5), X_4 =(5, 5, 2, 5), X_5 =(5, 4, 2, 5), X_6 =(5, 3, 2, 5), X_7 =(5, 5, 3, 5), X_8 =(5, 4, 3, 5), X_9 =(5, 3, 3, 5), X_{10} =(5, 2, 3, 5), X_{11} =(5, 5, 4, 5), X_{12} =(5, 4, 4, 5), X_{13} =(5, 3, 4, 5), X_{14} =(5, 2, 4, 5), X_{15} =(5, 1, 4, 5), X_{16} =(5, 5, 5, 5), X_{17} =(5, 4, 5, 5), X_{18} =(5, 3, 5, 5), X_{19} =(5, 2, 5, 5), X_{20} =(5, 1, 5, 5), X_{21} =(5, 0, 5, 5)}.

3. Find the set $\Omega_{min} = \{X | X$ is a minimal vector in $\Omega\}$.

   (a) $i = 1$,
   (b) $j = 2$,
   (c) $X_2 \leq X_1$ is false.
   (d) $X_2 > X_1$ is true, **so** $J = \phi \cup \{2\}$.
   (b) $j = 3$,
   (c) $X_3 \leq X_1$ is false.
   (d) $X_3 > X_1$ is false.
   (b) $j = 4$,
   (c) $X_4 \leq X_1$ is false.
   (d) $X_4 > X_1$ is true, **so** $J = \{2\} \cup \{4\}$.
   $\vdots$
   (g) $\Omega_{min} = \phi \cup \{X_1\}$
   (a) $i = 3$,

(b) $j = 5$,

$\vdots$

The result of Ω_{min} is
$\{X_1 = (5, 5, 0, 5), X_3 = (5, 4, 1, 5), X_6 = (5, 3, 2, 5), X_{10} = (5, 2, 3, 5), X_{15} = (5, 1, 4, 5), X_{21} = (5, 0, 5, 5)\}$.

Finally, the system performance index R_5 can be calculated in terms of six lower boundary points. At first, let $B_1 = \{X|X \geq X_1\}$, $B_2 = \{X|X \geq X_3\}$, $B_3 = \{X|X \geq X_6\}$, $B_4 = \{X|X \geq X_{10}\}$, $B_5 = \{X|X \geq X_{15}\}$ and $B_6 = \{X|X \geq X_{21}\}$. Then $R_5 = \Pr\{\bigcup_{i=1}^{6} B_i\}$. To calculate this, we find the probabilities of the capacities for the four persons from Table 3, where D_i maps the proper distribution based on the result of their examination respectively. Then, R_5 is figured by applying the inclusion-exclusion rule as in the following calculation. For convenience, we define X_{ir} means the r^{th} component of the vector X_i.

$$
\begin{aligned}
R_5 &= \Pr\{\textstyle\bigcup_{i=1}^{6} B_i\} \\
&= \textstyle\sum_{i=1}^{6} \Pr\{B_i\} - \sum_{1\leq i<j\leq 6} \Pr\{B_i \cap B_j\} + \sum_{1\leq i<j<k\leq 6} \Pr\{B_i \cap B_j \cap B_k\} \\
&- \textstyle\sum_{1\leq i<j<k<l\leq 6} \Pr\{B_i \cap B_j \cap B_k \cap B_l\} \\
&+ \textstyle\sum_{1\leq i<j<k<l<m\leq 6} \Pr\{B_i \cap B_j \cap B_k \cap B_l \cap B_m\} \\
&- \textstyle\sum_{1\leq i<j<k<l<m<n\leq 6} \Pr\{B_i \cap B_j \cap B_k \cap B_l \cap B_m \cap B_n\} \\
&= \textstyle\sum_{i=1}^{6} \prod_{r=1}^{4} \Pr\{x_r \geq X_{ir}\} \\
&- \textstyle\sum_{1\leq i<j\leq 6} \prod_{r=1}^{4} \Pr\{x_r \geq x_{wr} | x_{wr} = \max(X_{ir}, X_{jr})\} \\
&+ \textstyle\sum_{1\leq i<j<k\leq 6} \prod_{r=1}^{4} \Pr\{x_r \geq x_{wr} | x_{wr} = \max(X_{ir}, X_{jr}, X_{kr})\} \\
&- \textstyle\sum_{1\leq i<j<k<l\leq 6} \prod_{r=1}^{4} \Pr\{x_r \geq x_{wr} | x_{wr} = \max(X_{ir}, X_{jr}, X_{kr}, X_{lr})\} \\
&+ \textstyle\sum_{1\leq i<j<k<l<m\leq 6} \prod_{r=1}^{4} \Pr\{x_r \geq x_{wr} | x_{wr} = \max(X_{ir}, X_{jr}, X_{kr}, X_{lr}, X_{mr})\} \\
&- \textstyle\sum_{1\leq i<j<k<l<m<n\leq 6} \prod_{r=1}^{4} \Pr\{x_r \geq x_{wr} | x_{wr} = \max(X_{ir}, X_{jr}, X_{kr}, X_{lr}, X_{mr}, X_{nr})\} \\
&= 1.3476 - 0.7680 + 0.1652 - 0.0412 + 0.0085 - 0.0007 \\
&= 0.7114
\end{aligned}
$$

In the calculation, R_5 is 0.7114. The probability that the ERP system can complete at least 5 documents is 0.7114. Similarly, for more justification, Table 4 denotes the results of each step when d decreases to 4. It shows that R_4 increases to 0.9406, which is rational for this calculation. Further inspection of more complete patterns with respect to R_5 is illustrated in Table 5. These are cases of zero failure, one failure, two failures, three failures and all failures. These cases denote that more than two persons failed in the examination for the example system depicts an infeasible implementation since the R_5 dropped to 0.0025, 0.0147 and 0.0024, respectively. The key persons in this case are b_1 and b_4 who are responsible for the initiating and ending process respectively, since only their failures would cause the R_5 to drop to 0.0026 and 0.0025 respectively.

6. Conclusion

This paper proposed a method based on flow network model to evaluate the performance of an ERP system depending upon the results of an ERP examination of the company user involved. At first, the ERP system is proposed to be modeled by a stochastic-flow network model. Then, through the algorithm proposed in this paper, the performance index R_d is calculated. By the illustration of numerical examples, the proposed approach is easily to be

Table 4: The results of each step for $d = 4$

Step 1. Find $\mathbf{F}$	Step 2. Find Ω	Step 3. Find Ω_{min}	R_4
(0, 0, 0, 4), (0, 0, 1, 3), (0, 0, 2, 2), (0, 0, 3, 1), (0, 0, 4, 0), (0, 1, 0, 3), (0, 1, 1, 2), (0, 1, 2, 1), (0, 1, 3, 0), (0, 2, 0, 2), (0, 2, 1, 1), (0, 2, 2, 0), (0, 3, 0, 1), (0, 3, 1, 0), (0, 4, 0, 0), (1, 0, 0, 3), (1, 0, 1, 2), (1, 0, 2, 1), (1, 0, 3, 0), (1, 1, 0, 2), (1, 1, 1, 1), (1, 1, 2, 0), (1, 2, 0, 1), (1, 2, 1, 0), (1, 3, 0, 0), (2, 0, 0, 2), (2, 0, 1, 1), (2, 0, 2, 0), (2, 1, 0, 1), (2, 1, 1, 0), (2, 2, 0, 0), (3, 0, 0, 1), (3, 0, 1, 0), (3, 1, 0, 0), (4, 0, 0, 0)	(4, 4, 0, 4), (4, 4, 1, 4), (4, 3, 1, 4), (4, 4, 2, 4), (4, 3, 2, 4), (4, 2, 2, 4), (4, 4, 3, 4), (4, 3, 3, 4), (4, 2, 3, 4), (4, 1, 3, 4), (4, 4, 4, 4), (4, 3, 4, 4), (4, 2, 4, 4), (4, 1, 4, 4), (4, 0, 4, 4)	(4, 4, 0, 4), (4, 3, 1, 4), (4, 2, 2, 4), (4, 1, 3, 4), (4, 0, 4, 4)	0.9406

Table 5: The results of various examination patterns

Persons(Nodes)	b_1	b_2	b_3	b_4	R_5
Test 1	passed	passed	passed	passed	0.7433*
Test 2	failed	passed	passed	passed	0.0026
Test 3	passed	failed	passed	passed	0.7114*
Test 4	passed	passed	failed	passed	0.6993*
Test 5	passed	passed	passed	failed	0.0025
Test 6	failed	failed	passed	passed	0.0025
Test 7	passed	failed	failed	passed	0.0147
Test 8	passed	passed	failed	failed	0.0024
Test 9	failed	failed	failed	passed	0.0001
Test 10	passed	failed	failed	failed	0.0001
Test 11	failed	failed	failed	failed	0.0000

* denotes the significant value.

fulfilled and can be took place at the ERP pre-implementing stage to help making decision about the date of system online, or at a regular interval within the system execution to assess the ERP performance under the company's people floating.

References

[1] M. Al-Mashari, A. Al-Mudimigh and M. Zairi: Enterprise resource planning: a taxonomy of critical factors. *European Journal of Operational Research*, **146** (2003), 352–364.

[2] K. Amoako-Gyampah and A.F. Salam: An extension of the technology acceptance model in an ERP implementation environment. *Information and Management*, **41** (2004), 731–745.

[3] D. Chand, G. Hachey, J. Hunton, V. Owhoso and S. Vasudevan: A balanced scorecard based framework for assessing the strategic impacts of ERP systems. *Computers in Industry*, **56** (2005), 558–572.

[4] I.C. Chang, H.G. Hwang, M.C. Hung, S.L. Chen and D.C. Yen: A neural network evaluation model for ERP performance from SCM perspective to enhance enterprise competitive advantage. *Expert systems with applications*, doi:10.1016/j.eswa.2008.08.102

(2007).

[5] S. Dowlatshahi: Strategic success factors in enterprise resource-planning design and implementation: a case-study approach. *International Journal of Production Research*, **43** (2005), 3745–3771.

[6] L.R. Ford and D.R. Fulkerson: *Flows in Networks* (Princeton University Press, NJ, 1962).

[7] M.C. Jones and R. Young: ERP usage in practice: an empirical investigation. *Information Resources Management Journal*, **19** (2006), 23–42.

[8] H.Y. Lin, K.Y. Lai, W.L. Shiau, P.Y. Hsu, J.D. Leu, W.H. Tsai, M.S. Cheng and Y.W. Fan: The evaluation of post implementation ERP investment performance by DEA approach. *Journal of E-Business*, **6** (2004), 175–191.

[9] W.T. Lin, S.C. Chen, M.Y. Lin and H.H. Wu: A study on performance of introducing ERP to semiconductor related industries in Taiwan. *International Journal of Advanced Manufacturing Technology*, **29** (2006), 89–98.

[10] Y.-K. Lin: On a multicommodity stochastic-flow network with unreliable nodes subject to budget constraint. *European Journal of Operational Research*, **176** (2007), 347–360.

[11] Y.-K. Lin: Reliability evaluation for an information network with node failure under cost constraint. *IEEE Transactions on Systems, Man and Cybernetics - Part A: Systems and Humans*, **37** (2007), 180–188.

[12] Y.-K. Lin: Study on longer and shorter boundary duration vectors with arbitrary duration and cost values. *Journal of the Operations Research Society of Japan*, **50** (2007), 73–81.

[13] Y.-K. Lin: System capacity for a two-commodity multistate flow network with unreliable nodes and capacity weight. *Computers and Operations Research*, **34** (2007), 3043–3054.

[14] R. Sebastianelli and T.D. Rishel: Some survey results on ERP systems implementation. In Proceedings: *Annual Meeting of the Decision Sciences Institute* (Washington DC, 2003), 547–552.

[15] W.-H. Tsai, Y.-W. Fan, J.-D. Leu, L.-W. Chou and C.-C. Yang: The relationship between implementation variables and performance improvement of ERP systems. *International Journal of Technology Management*, **38** (2007), 350–373.

[16] F. Wu, C. Liu, H. Z. Li, K. Gao and J. Tian: The benefits evaluation of ERP project investment based on real options. In Proceedings: *IEEE International Conference on Systems, Man and Cybernetics* (vol. 5, Taipei, 2007), 4078–4083.

[17] J. Xue: On multistate system analysis. *IEEE Transactions on Reliability*, **34** (1985), 329–337.

[18] C.-C. Yang, W.-T. Lin, F.-Y. Pai and T.-M. Yeh: The use of fuzzy measures in a performance-evaluation model for ERP implementation among Taiwanese semiconductor manufacturers. *International Journal of Production Research*, **45** (2007), 4735–4752.

[19] C.-S. Yu: Causes influencing the effectiveness of the post-implementation ERP system. *Industrial Management and Data Systems*, **105** (2005), 115–132.

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