A fuzzy goal programming model for strategic information technology investment assessment

Faramak Zandi
Industrial Engineering Department, Faculty of Technology and Engineering, Alzahra University, Tehran, Iran, and
Madjid Tavana
Management Department, Lindback Distinguished Chair of Information Systems, La Salle University, Philadelphia, Pennsylvania, USA

Abstract

Purpose – The high expenditures in information technology (IT) and the growing usage that penetrates the core of business have resulted in a need to effectively and efficiently evaluate strategic IT investments in organizations. The purpose of this paper is to propose a novel two-dimensional approach that determines the deferrable strategy with the most value by maximizing the real option values while minimizing the risks associated with each alternative strategy.

Design/methodology/approach – In the proposed approach, first, the deferrable investment strategies are prioritized according to their values using real option analysis (ROA). Then, the risks associated with each investment strategy are quantified using the group fuzzy analytic hierarchy process. Finally, the values associated with the two dimensions are integrated to determine the deferrable IT investment strategy with the most value using a fuzzy preemptive goal programming model.

Findings – Managers face the difficulty that most IT investment projects are inherently risky, especially in a rapidly changing business environment. The paper proposes a framework that can be used to evaluate IT investments based on the real option concept. This simple, intuitive, generic and comprehensive approach incorporates the linkage among economic value, real option value and IT investments that could lead to a better-structured decision process.

Originality/value – In contrast to the traditional ROA literature, the approach contributes to the literature by incorporating a risk dimension parameter. The paper emphasizes the importance of categorizing risk management in IT investment projects since some risk cannot be eliminated.

Keywords Fuzzy control, Information technology, Value analysis, Risk analysis, Analytical hierarchy process

Paper type Research paper

1. Introduction

Information technology (IT) investments represent the largest capital expenditure items for many organizations and have a tremendous impact on productivity by reducing costs, improving quality and increasing value to customers. As a result, many organizations continue to invest large sums of money in IT in anticipation of a material return on their investment (Willcocks and Lester, 1996). The selection of appropriate IT investments has

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been one of the most significant business challenges of the last decade. Powell (1992) has studied the similarities and differences between IT investments and other capital investments in organizations. He notes that IT investments are undertaken by organizations to gain competitive advantage, to improve productivity, to enable new ways of managing and organizing and to develop new businesses. Appropriate strategic IT investments can help companies gain and sustain a competitive advantage (Melville *et al.*, 2004). However, many large IT investment projects often do not meet original expectations of cost, time or benefits. The rapid growth of IT investments has imposed tremendous pressure on management to take into consideration risks and payoffs promised by the investment in their decision making.

A review of the current literature offers several IT investment evaluation methods that provide frameworks for the quantification of risks and benefits. The net present value (NPV) (Hayes and Abernathy, 1980; Kaplan and Atkinson, 1998), return on investment (Brealey and Myers, 1998; Farbey *et al.*, 1993; Kumar, 2002; Luehrman, 1997), cost benefit analysis (Schniederjans *et al.*, 2004), information economics (Bakos and Kemerer, 1992; Parker and Benson, 1989) and return on management (Chen *et al.*, 2006; Stix and Reiner, 2004; Strassmann, 1997) are among most widely used methods to assess the risks and payoffs associated with IT investments.

In addition to the above mentioned traditional quantitative approaches, there is a stream of research studies which emphasizes real option analysis (ROA). The ROA differs from the traditional methods in terms of priceability of the underlying investment project (McGrath, 1997). With the traditional methods, the underlying investment project of an option is priced as known (Black and Scholes, 1973) while in IT investment situations the price of an underlying investment is rarely known (McGrath, 1997). The ROA uses three basic types of data:

(1) current and possible future investment options;

(2) the desired capabilities sought by the organization; and

(3) the relative risks and costs of other IT investment options that could be used.

The method can help assess the risks associated with IT investment decisions by taking into consideration the changing nature of business strategies and organizational requirements.

The real options are commonly valued with the Black-Scholes option pricing formula (Black and Scholes, 1973, 1974), the binomial option valuation method (Cox *et al.*, 1979) and Monte-Carlo methods (Boyle, 1977). These methods assume that the underlying markets can be imitated accurately as a process. Although this assumption may hold for some quite efficiently traded financial securities, it may not hold for real investments that do not have existing markets (Collan *et al.*, 2009). Recently, a simple novel approach to ROA called the Datar-Mathews method (Datar and Mathews, 2004, 2007; Mathews and Salmon, 2007) was proposed where the real option value is calculated from a pay-off distribution, derived from a probability distribution of the NPV for an investment project generated with a Monte-Carlo simulation. This approach does suffer from the market process assumptions associated with the Black-Scholes method (Black and Scholes, 1974).

When valuating an investment using ROA, it is required to estimate several parameters (i.e. expected payoffs and costs or investment deferral time). However, the estimation of uncertain parameters in this valuation process is often very challenging. Most traditional methods use probability theory in their treatment of uncertainty.

Fuzzy logic and fuzzy sets can represent ambiguous, uncertain or imprecise information in ROA by formalizing inaccuracy in human decision making (Collan *et al.*, 2009). For example, fuzzy sets allow for graduation of belonging in future cash-flow estimation (i.e. future cash flow at year 5 is about 5,000 dollars). Fuzzy set algebra developed by Zadeh (1965) is the formal body of theory that allows the treatment of imprecise estimates in uncertain environments.

In recent years, several researchers have combined fuzzy sets theory with ROA. Carlsson and Fullér (2003) introduced a (heuristic) real option rule in a fuzzy setting, where the present values of expected cash flows and expected costs are estimated by trapezoidal fuzzy numbers. Chen *et al.* (2007) developed a comprehensive but simple methodology to evaluate IT investment in a nuclear power station based on fuzzy risk analysis and real option approach. Frode (2007) used the conceptual real option framework of Dixit and Pindyck (1994) to estimate the value of investment opportunities in the Norwegian hydropower industry. Villani (2008) combined two successful theories, namely real options and game theory, to value the investment opportunity and the value of flexibility as a real option while analyzing the competition with game theory. Collan *et al.* (2009) presented a new method for real option valuation using fuzzy numbers. Their method considered the dynamic nature of the profitability assessment, that is, the assessment changes when information changes. As cash flows taking place in the future come closer, information changes and uncertainty is reduced. Chrysafis and Papadopoulos (2009) presented an application of a new method of constructing fuzzy estimators for the parameters of a given probability distribution function using statistical data. Wang and Hwang (2007) developed a fuzzy research and development portfolio selection model to hedge against the environmental uncertainties. They applied fuzzy set theory to model uncertain and flexible project information. Since traditional project valuation methods often underestimate the risky project, a fuzzy compound-options model was used to evaluate the value of each project. Their portfolio selection problem was formulated as a fuzzy zero-one integer programming model that could handle both uncertain and flexible parameters and determine the optimal project portfolio. A new transformation method based on qualitative possibility theory was developed to convert the fuzzy portfolio selection model into a crisp mathematical model from the risk-averse perspective. The transformed model was solved by an optimization technique.

We propose a novel two-dimensional approach that determines the deferrable strategy with the most value by maximizing the real option values while minimizing the risks associated with each alternative strategy. First, the deferrable investment strategies are prioritized according to their values using the ROA. Then, the risks associated with each investment strategy are quantified using the group fuzzy analytic hierarchy process (GFAHP). Finally, the values associated with the two dimensions are integrated to determine the deferrable IT investment strategy with the most value using a fuzzy preemptive goal programming model. The proposed framework:

- addresses the gaps in the IT investment assessment literature on the effective and efficient evaluation of IT investment strategies;
- provides a comprehensive and systematic framework that combines ROA with a group fuzzy approach to assess IT investment strategies;
- considers fuzzy logic and fuzzy sets to represent ambiguous, uncertain or imprecise information; and

- it uses a real-world case study to demonstrate the applicability of the proposed framework and exhibit the efficacy of the procedures and algorithms.

This paper is organized into five sections. In Section 2, we illustrate the details of the proposed framework followed by a case study in Section 3. In Section 4, we present discussion and practical perspectives and in Section 5, we conclude with our conclusions and future research directions.

2. The proposed framework

The mathematical notations and definitions used in our model are presented in the Appendix. The framework shown in Figure 1 is proposed to assess alternative IT investment strategies. The framework consists of several steps modularized into five phases.

Phase 1: establishment of the IT investment board

We institute a strategic IT investment board to acquire pertinent investment information. Executive management is typically responsible for creating the board, specifying its responsibilities and defining its resources. Let us assume that l strategic IT investment board members are selected to participate in the evaluation process:

$$\underline{ITIB} = [(ITIB)_1, (ITIB)_2, \ldots, (ITIB)_k, \ldots, (ITIB)_l]$$

Phase 2: identification of the IT investment strategies

Next, the strategic IT investment board identifies a set of alternative deferrable IT investment strategies. Let us assume that n alternative IT investments with the maximum deferral time of T_m are under consideration:

$$\underline{a} = [a_1, a_2, \ldots, a_i, \ldots a_n]$$

Phase 3: prioritization of the IT investment strategies: real option considerations

In this phase, the real options equations suggested by Dos Santos (1994) are used to prioritize IT investments strategies. This phase is divided into the following three steps.

Step 3.1: construction of the individual real option matrices. The following individual real option matrices are given by each strategic IT investment board member:

$$\tilde{A}^k_{RO_1} = \begin{array}{c c} & \begin{array}{cccccccc} \tilde{B}(T_1) & \tilde{B}(T_2) & \ldots & \tilde{B}(T_m) & \tilde{C}(T_1) & \tilde{C}(T_2) & \ldots & \tilde{C}(T_m) \end{array} \\ \begin{array}{c} a_1 \\ a_2 \\ \vdots \\ a_n \end{array} & \begin{bmatrix} \tilde{B}^k_1(T_1) & \tilde{B}^K_1(T_2) & \ldots & \tilde{B}^k_1(T_m) & \tilde{C}^k_1(T_1) & \tilde{C}^k_1(T_2) & \ldots & \tilde{C}^k_1(T_m) \\ \tilde{B}^k_2(T_1) & \tilde{B}^k_2(T_2) & \ldots & \tilde{B}^k_2(T_m) & \tilde{C}^k_2(T_1) & \tilde{C}^k_2(T_2) & \ldots & \tilde{C}^k_2(T_m) \\ \vdots & \vdots & \ldots & \vdots & \vdots & \vdots & \ldots & \vdots \\ \tilde{B}^k_n(T_1) & B^K_n(T_2) & \ldots & B^K_n(T_m) & \tilde{C}^k_n(T_m) & C^k_n(T_2) & \ldots & C^k_n(T_m) \end{bmatrix} \end{array} \quad (1)$$

For $k = 1, 2, \ldots, l$.

Fuzzy numbers are often represented by triangular or trapezoidal fuzzy sets. In this study, we use trapezoidal fuzzy sets. A major advantage of trapezoidal fuzzy numbers is

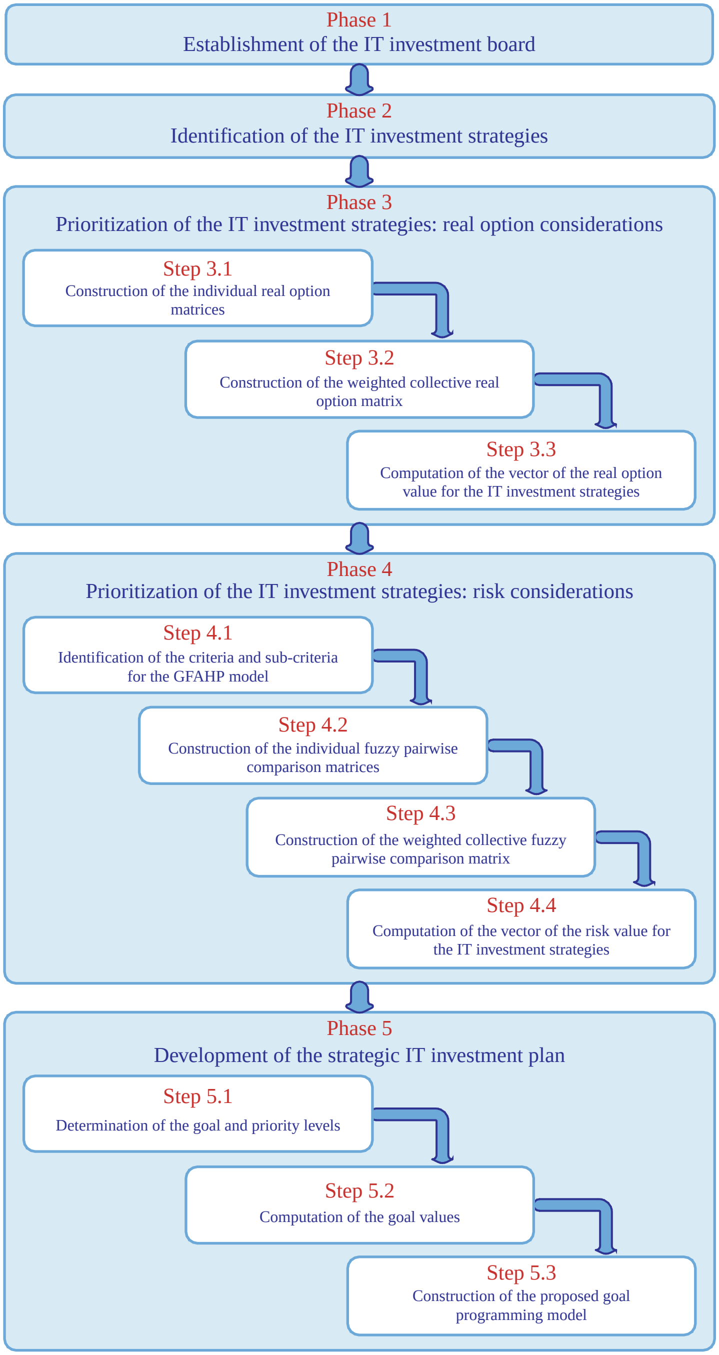


Figure 1.
The proposed framework

that many operations based on the max-min convolution can be replaced by direct arithmetic operations (Dubois and Prade, 1988). The following trapezoidal fuzzy numbers are used for the individual fuzzy present values of the expected cash flows and the cost of the ith IT investment at time T_j by strategic IT investment board member $(ITIB)_k$:

$$\begin{aligned}\tilde{B}_i^k(T_j) &= \left(\left(B_i^k(T_j)\right)^o, \left(B_i^k(T_j)\right)^\alpha, \left(B_i^k(T_j)\right)^\beta, \left(B_i^k(T_j)\right)^\gamma\right)\\ \tilde{C}_i^k &= \left(\left(C_i^k(T_j)\right)^o, \left(C_i^k(T_j)\right)^\alpha, \left(C_i^k(T_j)\right)^\beta, \left(C_i^k(T_j)\right)^\gamma\right)\end{aligned} \tag{2}$$

For $j = 1, 2, \ldots, m$.

That is, we have the following intervals:

$\left\lfloor \left(B_i^k(T_j)\right)^o, \left(B_i^k(T_j)\right)^\alpha \right\rfloor$	the most possible values for the expected cash flows of the ith IT investment at time T_j evaluated by strategic IT investment board member $(ITIB)_k$.
$\left(\left(B_i^k(T_j)\right)^o + \left(B_i^k(T_j)\right)^\gamma\right)$	the upward potential for the expected cash flows of the ith IT investment at time T_j evaluated by strategic IT investment board member $(ITIB)_k$.
$\left(\left(B_i^k(T_j)\right)^o - \left(B_i^k(T_j)\right)^\beta\right)$	the downward potential for the expected cash flows of the ith IT investment at time T_j evaluated by strategic IT investment board member $(ITIB)_k$.
$\left\lfloor \left(C_i^k(T_j)\right)^o, \left(C_i^k(T_j)\right)^\alpha \right\rfloor$	the most possible values of the expected cost of the ith IT investment at time T_j evaluated by strategic IT investment board member $(ITIB)_k$.
$\left(\left(C_i^k(T_j)\right)^o + \left(C_i^k(T_j)\right)^\gamma\right)$	the upward potential for the expected cost of the ith IT investment at time T_j evaluated by strategic IT investment board member $(ITIB)_k$.
$\left(\left(C_i^k(T_j)\right)^o - \left(C_i^k(T_j)\right)^\beta\right)$	the downward potential for the expected cash flows of the ith IT investment at time T_j evaluated by strategic IT investment board member $(ITIB)_k$.

Consequently, substituting equation (2) into matrix (1), the individual real option matrices can be rewritten as:

$$\tilde{A}_{RO_1}^k(T_i) = \begin{array}{c|c} & \begin{array}{cc} \qquad\tilde{B}(T_i)\qquad & \qquad\tilde{C}(T_i)\qquad \end{array} \\ \begin{array}{c} a_1 \\ a_2 \\ \vdots \\ a_n \end{array} & \left[\begin{array}{cc} \left(\left(B_1^k(T_i)\right)^o, \left(B_1^k(T_i)\right)^\alpha, \left(B_1^k(T_i)\right)^\beta, \left(B_1^k(T_i)\right)^\gamma\right) & \left(\left(C_1^k(T_i)\right)^o, \left(C_1^k(T_i)\right)^\alpha, \left(C_1^k(T_i)\right)^\beta, \left(C_1^k(T_i)\right)^\gamma\right) \\ \left(\left(B_2^k(T_i)\right)^o, \left(B_2^k(T_i)\right)^\alpha, \left(B_2^k(T_i)\right)^\beta, \left(B_2^k(T_i)\right)^\gamma\right) & \left(\left(C_2^k(T_i)\right)^o, \left(C_2^k(T_i)\right)^\alpha, \left(C_2^k(T_i)\right)^\beta, \left(C_2^k(T_i)\right)^\gamma\right) \\ \vdots & \vdots \\ \left(\left(B_n^k(T_i)\right)^o, \left(B_n^k(T_i)\right)^\alpha, \left(B_n^k(T_i)\right)^\beta, \left(B_n^k(T_i)\right)^\gamma\right) & \left(\left(C_n^k(T_i)\right)^o, \left(C_n^k(T_i)\right)^\alpha, \left(C_n^k(T_i)\right)^\beta, \left(C_n^k(T_i)\right)^\gamma\right) \end{array}\right] \end{array} \tag{3}$$

Step 3.2: construction of the weighted collective real option matrix. This framework allows for assigning different voting power weights given to each investment board member:

$$\underline{W}(vp) = [w(vp)_1, w(vp)_2, \ldots, w(vp)_j, \ldots, w(vp)_l] \tag{4}$$

Therefore, in order to form a fuzzy weighted collective real option matrix, the individual fuzzy real option matrices will be aggregated by the voting powers as follows:

$$\tilde{A}_{RO_2}(T_i) = \begin{array}{c} \\ a_1 \\ a_2 \\ \vdots \\ a_n \end{array} \begin{array}{c} \begin{array}{cc} \tilde{B}(T_i) & \tilde{C}(T_i) \end{array} \\ \begin{bmatrix} \tilde{B}_1(T_i) & \tilde{C}_1(T_i) \\ \tilde{B}_2(T_i) & \tilde{C}_2(T_i) \\ \vdots & \vdots \\ \tilde{B}_n(T_i) & \tilde{C}_n(T_i) \end{bmatrix} \end{array} \tag{5}$$

where:

$$\tilde{B}_i(T_i) = \frac{\sum_{k=1}^{l} (w(vp)_k) \left(\tilde{B}_i^k(T_i) \right)}{\sum_{k=1}^{l} w(vp)_k} \tag{6}$$

$$\tilde{C}_i(T_i) = \frac{\sum_{k=1}^{l} (w(vp)_k) \left(\tilde{C}_i^k(T_i) \right)}{\sum_{k=1}^{l} w(vp)_k} \tag{7}$$

Step 3.3: Computation of the vector of the real option value for the IT investment strategies. The real option values of the investment strategies at times $T_1, T_2, \ldots, T_m$ can be determined by the following fuzzy real option value matrix:

$$\tilde{A}_{FROV} = \begin{array}{c} \\ a_1 \\ a_2 \\ \vdots \\ a_4 \end{array} \begin{array}{c} \begin{array}{cccc} T_1 & T_2 & \ldots & T_m \end{array} \\ \begin{bmatrix} FROV_1(T_1) & FROV_1(T_2) & \ldots & FROV_1(T_m) \\ FROV_2(T_1) & FROV_2(T_2) & \ldots & FROV_2 T_m \\ \vdots & \vdots & \ldots & \vdots \\ FROV_n(T_1) & FROV_n(T_2) & \ldots & FROV_n T_m \end{bmatrix} \end{array} \tag{8}$$

or:

$$\tilde{A}_{FROV}(T_i) = \begin{array}{c} a_1 \\ a_2 \\ \vdots \\ a_4 \end{array} \begin{bmatrix} \tilde{B}_1(T_i) \cdot e^{-\delta T_i} \cdot N(D_{11}(T_i)) - \tilde{C}_1(T_i) \cdot e^{-rT_i} \cdot N(D_{21}(T_i)) \\ \tilde{B}_2(T_i) \cdot e^{-\delta T_i} \cdot N(D_{12}(T_i)) - \tilde{C}_2(T_i) \cdot e^{-rT_i} \cdot N(D_{22}(T_i)) \\ \vdots \\ \tilde{B}_n(T_i) \cdot e^{-\delta T_i} \cdot N(D_{1n}(T_i)) - \tilde{C}_n(T_i) \cdot e^{-rT_i} \cdot N(D_{2n}(T_i)) \end{bmatrix} = \begin{bmatrix} FROV_1(T_i) \\ FROV_2(T_i) \\ \vdots \\ FROV_n(T_i) \end{bmatrix} \tag{9}$$

where the IT investment strategy ith cumulative normal probabilities for the $D_1$and D_2 are as follows:

$$A_{RO_3}(T_i) = \begin{array}{c} \\ a_1 \\ a_2 \\ \vdots \\ a_n \end{array} \begin{array}{c} \begin{array}{cc} N(D_1(T_i)) & N(D_2(T_i)) \end{array} \\ \begin{bmatrix} N(D_{11}(T_i)) & N(D_{21}(T_i)) \\ N(D_{12}(T_i)) & N(D_{22}(T_i)) \\ \vdots & \vdots \\ N(D_{1n}(T_i)) & N(D_{2n}(T_i)) \end{bmatrix} \end{array} \tag{10}$$

$$A_{RO_4}(T) = \begin{array}{c} \\ a_1 \\ a_2 \\ \vdots \\ a_n \end{array} \begin{array}{c} \begin{array}{cc} D_1(T_i) & D_2(T_i) \end{array} \\ \begin{bmatrix} D_{11}(T_i) & D_{21}(T_i) \\ D_{12}(T_i) & D_{22}(T_i) \\ \vdots & \vdots \\ D_{1n}(T_i) & D_{2n}(T_i) \end{bmatrix} \end{array} \tag{11}$$

or equivalently:

$$A_{RO_4}(T_i) = \begin{array}{c} \\ a_1 \\ a_2 \\ \vdots \\ a_n \end{array} \begin{array}{c} \begin{array}{cc} D_1(T_i) & D_2(T_i) \end{array} \\ \begin{bmatrix} \frac{Ln(E(\tilde{B}_1(T_i))/E(\tilde{C}_1(T_i)))+\left((r_1-\delta_1+\sigma_1^2(T_i))/2\right)\cdot T_i}{\sigma_1(T_i)\sqrt{T_i}} & \frac{Ln(E(\tilde{B}_1(T_i))/E(\tilde{C}_1(T_i)))+\left((r_1-\delta_1-\sigma_1^2(T_i))/2\right)\cdot T_i}{\sigma_1^2(T_i)\sqrt{T_i}} \\ \frac{Ln(E(\tilde{B}_2(T_i))/E(\tilde{C}_2(T_i)))+\left((r_2-\delta_2+\sigma_2^2(T_i))/2\right)\cdot T_i}{\sigma_2(T_i)\sqrt{T_i}} & \frac{Ln(E(\tilde{B}_2(T_i))/E(\tilde{C}_2(T_i)))+\left((r_2-\delta_2-\sigma_2^2(T_i))/2\right)\cdot T_i}{\sigma_2(T_i)\sqrt{T}} \\ \vdots & \vdots \\ \frac{Ln(E(\tilde{B}_n(T_i))/E(\tilde{C}_n(T_i)))+\left((r_n-\delta_n+\sigma_n^2(T_i))/2\right)\cdot T_i}{\sigma_n(T_i)\sqrt{T_i}} & \frac{Ln(E(\tilde{B}_n(T_i))/E(\tilde{C}_n(T_i)))+\left((r_n-\delta_n-\sigma_n^2(T_i))/2\right)\cdot T_i}{\sigma_n(T_i)\sqrt{T_i}} \end{bmatrix} \end{array} \tag{12}$$

where E and σ^2 denote the possibilistic mean value and possibilistic variance operators as follows:

$$A_{RO_5}(T_i) = \begin{array}{c} \\ a_1 \\ a_2 \\ \vdots \\ a_n \end{array} \begin{array}{c} \begin{array}{ccc} E(\tilde{B}(T_i)) & E(\tilde{C}(T_i)) & \sigma^2(T_i) \end{array} \\ \begin{bmatrix} E(\tilde{B}_1(T_i)) & E(\tilde{C}_1(T_i)) & \sigma_1^2(T_i) \\ E(\tilde{B}_2(T_i)) & E(\tilde{C}_2(T_i)) & \sigma_2^2(T_i) \\ \vdots & \vdots & \vdots \\ E(\tilde{B}_n(T_i)) & E(\tilde{C}_n(T_i)) & \sigma_n^2(T_i) \end{bmatrix} \end{array} \tag{13}$$

Since $\tilde{B}_i$ and $\tilde{C}_i$ are trapezoidal fuzzy numbers, we use the formulas proposed by Carlsson and Fullér (2003) to find their expected value and the variance:

$$\begin{aligned} E(\tilde{B}_i(T_j)) &= \frac{(B(T_j))^o + (B(T_j))^\alpha}{2} + \frac{(B(T_j))^\gamma - (B(T_j))^\beta}{6} \\ E(\tilde{C}_i(T_j)) &= \frac{(C(T_j))^o + (C(T_j))^\alpha}{2} + \frac{(C(T_j))^\gamma - (C(T_j))^\beta}{6} \\ \sigma_i^2(T_j) &= \frac{((B(T_j))^\alpha - (B(T_j))^o)^2}{4} + \frac{((B(T_j))^\alpha - (B(T_j))^o)((B(T_j))^\beta + (B(T_j))^\gamma)}{6} \\ &\quad + \frac{((B(T_j))^\beta + (B(T_j))^\gamma)^2}{24} \end{aligned} \tag{14}$$

Phase 4: prioritization of the IT investment strategies: risk considerations
In this phase, the strategic IT investment board identifies the evaluation criteria and sub-criteria and uses GFAHP to measure the risk for each criterion and sub-criterion associated with the investment projects. This phase is divided into the following four steps.

Step 4.1: identification of the criteria and sub-criteria for the GFAHP model. In this step, the strategic IT investment board will determine a list of the criteria and sub-criteria for the GFAHP model. Let $c_1, c_2, \ldots, c_p$ and $sc_1, sc_2, \ldots, sc_q$ be the criteria and sub-criteria, respectively.

Step 4.2: construction of the individual fuzzy pairwise comparison matrices. The hierarchal structure for ranking the IT Investments strategies in the risk dimension consists of four levels. The top level consists of a single element and each element of a given level dominates or covers some or all of the elements in the level immediately below. At the second level, the individual fuzzy pairwise comparison matrix of the p criteria of IT investment risk evaluated by strategic IT investment board member $(ITIB)_k$ will be as follows:

$$\left(\tilde{A}_R^2\right)^k = \begin{array}{c} \\ c_1 \\ c_2 \\ \vdots \\ c_p \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \ldots & c_p \end{array} \\ \begin{bmatrix} \tilde{b}_{11}^k & \tilde{b}_{12}^k & \ldots & \tilde{b}_{1p}^k \\ \tilde{b}_{21}^k & \tilde{b}_{22}^k & \ldots & \tilde{b}_{2p}^k \\ \vdots & \vdots & \ldots & \vdots \\ \tilde{b}_{p1}^k & \tilde{b}_{p2}^k & \ldots & \tilde{b}_{pp}^k \end{bmatrix} \end{array} \tag{15}$$

Let the individual fuzzy comparison qualification between criteria i and j evaluated by strategic IT investment board member $(ITIB)_k$ be the following trapezoidal fuzzy numbers:

$$\tilde{b}_{ij}^k = \left(\left(b_{ij}^k\right)^o, \left(b_{ij}^k\right)^\alpha, \left(b_{ij}^k\right)^\beta, \left(b_{ij}^k\right)^\gamma \right) \tag{16}$$

Consequently, substituting equation (18) into matrix (17), the individual fuzzy comparison qualification between criteria i and j evaluated by strategic IT investment board member $(ITIB)_k$ can be rewritten as:

$$
(\tilde{A}_R^2)^k = \begin{array}{c} \\ c_1 \\ c_2 \\ \vdots \\ c_p \end{array}
\begin{array}{c} \begin{array}{cccc} C_1 & c_2 & \dots & C_p \end{array} \\
\begin{bmatrix}
((b_{11}^k)^o,(b_{11}^k)^\alpha,(b_{11}^k)^\beta,(b_{11}^k)^\gamma) & ((b_{12}^k)^o,(b_{12}^k)^\alpha,(b_{12}^k)^\beta,(b_{12}^k)^\gamma) & \dots & ((b_{1p}^k)^o,(b_{1p}^k)^\alpha,(b_{1p}^k)^\beta,(b_{1p}^k)^\gamma) \\
((b_{21}^k)^o,(b_{21}^k)^\alpha,(b_{21}^k)^\beta,(b_{21}^k)^\gamma) & ((b_{22}^k)^o,(b_{22}^k)^\alpha,(b_{22}^k)^\beta,(b_{22}^k)^\gamma) & \dots & ((b_{2p}^k)^o,(b_{2p}^k)^\alpha,(b_{2p}^k)^\beta,(b_{2p}^k)^\gamma) \\
\vdots & \vdots & \dots & \vdots \\
((b_{p1}^k)^o,(b_{p1}^k)^\alpha,(b_{p1}^k)^\beta,(b_{p1}^k)^\gamma) & ((b_{p2}^k)^o,(b_{p2}^k)^\alpha,(b_{p2}^k)^\beta,(b_{p2}^k)^\gamma) & \dots & ((b_{pp}^k)^o,(b_{pp}^k)^\alpha,(b_{pp}^k)^\beta,(b_{pp}^k)^\gamma)
\end{bmatrix} \end{array} \tag{17}
$$

At the third level, the individual fuzzy pairwise comparison matrix of IT investment risk sub-criteria with respect to p IT investment risk criteria evaluated by strategic IT investment board member $(ITIB)_k$ will be as follows:

$$
\left(\tilde{A}_R^3\right)^k = \begin{array}{c|cccc}
 & sc_1 & sc_2 & \dots & sc_q \\ \hline
sc_1 & \left(\tilde{d}_{11}^k\right)_P & \left(\tilde{d}_{12}^k\right)_P & \dots & \left(\tilde{d}_{1q}^k\right)_P \\
sc_2 & \left(\tilde{d}_{21}^k\right)_P & \left(\tilde{d}_{22}^k\right)_P & \dots & \left(\tilde{d}_{2q}^k\right)_P \\
\vdots & \vdots & \vdots & \dots & \vdots \\
sc_q & \left(\tilde{d}_{q1}^k\right)_P & \left(\tilde{d}_{q2}^k\right)_P & \dots & \left(\tilde{d}_{qq}^k\right)_P
\end{array} \tag{18}
$$

The individual fuzzy comparison qualification between sub-criterions i with sub-criterion j with respect to criterion p evaluated by strategic IT investment board member $(ITIB)_k$ are the following trapezoidal fuzzy numbers:

$$
\left(\tilde{a}_{ij}^k\right)_p = \left(\left(d_{ij}^k\right)^o, \left(d_{ij}^k\right)^\alpha, \left(d_{ij}^k\right)^\beta, \left(d_{ij}^k\right)^\gamma\right)_p \tag{19}
$$

Therefore, we have:

$$
(\tilde{A}_R^3)^k = \begin{array}{c} \\ sc_1 \\ sc_2 \\ \vdots \\ sc_q \end{array}
\begin{array}{c} \begin{array}{cccc} sc_1 & sc_2 & \dots & sc_q \end{array} \\
\begin{bmatrix}
((d_{11}^k)^o,(d_{11}^k)^\alpha,(d_{11}^k)^\beta,(d_{11}^k)^\gamma)_p & ((d_{12}^k)^o,(d_{12}^k)^\alpha,(d_{12}^k)^\beta,(d_{12}^k)^\gamma)_p & \dots & ((d_{1q}^k)^o,(d_{1q}^k)^\alpha,(d_{1q}^k)^\beta,(d_{1q}^k)^\gamma)_p \\
((d_{21}^k)^o,(d_{21}^k)^\alpha,(d_{21}^k)^\beta,(d_{21}^k)^\gamma)_p & ((d_{22}^k)^o,(d_{22}^k)^\alpha,(d_{22}^k)^\beta,(d_{22}^k)^\gamma)_p & \dots & ((d_{2q}^k)^o,(d_{2q}^k)^\alpha,(d_{2q}^k)^\beta,(d_{2q}^k)^\gamma) \\
\vdots & \vdots & \dots & \vdots \\
((d_{q1}^k)^o,(d_{q1}^k)^\alpha,(d_{q1}^k)^\beta,(d_{q1}^k)^\gamma)_p & ((d_{q2}^k)^o,(d_{q2}^k)^\alpha,(d_{q2}^k)^\beta,(d_{q2}^k)^\gamma)_p & \dots & ((d_{qq}^k)^o,(d_{qq}^k)^\alpha,(d_{qq}^k)^\beta,(d_{qq}^k)^\gamma)_p
\end{bmatrix} \end{array} \tag{20}
$$

At the fourth level, the individual fuzzy pairwise comparison matrix of n IT investment strategies with respect to q IT investment risk sub-criteria evaluated by strategic IT investment board member $(ITIB)_k$ will be as follows:

$$\left(\tilde{A}_R^4\right)^k = \begin{array}{cc} & \begin{array}{cccc} a_1 & a_2 & \cdots & a_n \end{array} \\ \begin{array}{c} a_1 \\ a_2 \\ \vdots \\ a_n \end{array} & \begin{bmatrix} \left(\tilde{r}_{11}^k\right)_q & \left(\tilde{r}_{12}^k\right)_q & \cdots & \left(\tilde{r}_{1n}^k\right)_q \\ \left(\tilde{r}_{21}^k\right)_q & \left(\tilde{r}_{22}^k\right)_q & \cdots & \left(\tilde{r}_{2n}^k\right)_q \\ \vdots & \vdots & \cdots & \vdots \\ \left(\tilde{r}_{n1}^k\right)_q & \left(\tilde{r}_{n2}^k\right)_q & \cdots & \left(\tilde{r}_{nn}^k\right)_q \end{bmatrix} \end{array} \tag{21}$$

The individual fuzzy comparison qualification between IT investment strategies *i* with IT investment strategy *j* with respect to sub-criterion *q* evaluated by strategic IT investment board member $(ITIB)_k$ are the following trapezoidal fuzzy numbers:

$$\left(\tilde{r}_{ij}^k\right)_q = \left(\left(r_{ij}^k\right)^o, \left(r_{ij}^k\right)^\alpha, \left(r_{ij}^k\right)^\beta, \left(r_{ij}^k\right)^\gamma\right)_q \tag{22}$$

or equivalently:

$$(\tilde{A}_R^4)^k = \begin{array}{cc} & \begin{array}{cccc} a_1 & a_2 & \cdots & a_n \end{array} \\ \begin{array}{c} a_1 \\ a_2 \\ \vdots \\ a_n \end{array} & \begin{bmatrix} ((r_{11}^k)^o,(r_{11}^k)^\alpha,(r_{11}^k)^\beta,(r_{11}^k)^\gamma)_q & ((r_{12}^k)^o,(r_{12}^k)^\alpha,(r_{12}^k)^\beta,(r_{12}^k)^\gamma)_q & \cdots & ((r_{1n}^k)^o,(r_{1n}^k)^\alpha,(r_{1n}^k)^\beta,(r_{1n}^k)^\gamma)_q \\ ((r_{21}^k)^o,(r_{21}^k)^\alpha,(r_{21}^k)^\beta,(r_{21}^k)^\gamma)_q & ((r_{22}^k)^o,(r_{22}^k)^\alpha,(r_{22}^k)^\beta,(r_{22}^k)^\gamma)_q & \cdots & ((r_{2n}^k)^o,(r_{2n}^k)^\alpha,(r_{2n}^k)^\beta,(r_{2n}^k)^\gamma)_q \\ \vdots & \vdots & \cdots & \vdots \\ ((r_{n1}^k)^o,(r_{n1}^k)^\alpha,(r_{n1}^k)^\beta,(r_{n1}^k)^\gamma)_q & ((r_{n2}^k)^o,(r_{n2}^k)^\alpha,(r_{n2}^k)^\beta,(r_{n2}^k)^\gamma)_q & \cdots & ((r_{nn}^k)^o,(r_{nn}^k)^\alpha,(r_{nn}^k)^\beta,(r_{nn}^k)^\gamma)_q \end{bmatrix} \end{array} \tag{23}$$

Step 4.3: construction of the weighted collective fuzzy pairwise comparison matrix. At the second level, the fuzzy weighted collective pairwise comparison matrix of *p* IT investment risk criteria will be as follows:

$$\tilde{A}_R^2 = \begin{array}{cc} & \begin{array}{cccc} c_1 & c_2 & \cdots & c_p \end{array} \\ \begin{array}{c} c_1 \\ c_2 \\ \vdots \\ c_p \end{array} & \begin{bmatrix} ((b_{11})^o,(b_{11})^\alpha,(b_{11})^\beta,(b_{11})^\gamma) & ((b_{12})^o,(b_{12})^\alpha,(b_{12})^\beta,(b_{12})^\gamma) & \cdots & ((b_{1p})^o,(b_{1p})^\alpha,(b_{1p})^\beta,(b_{1p})^\gamma) \\ ((b_{21})^o,(b_{21})^\alpha,(b_{21})^\beta,(b_{21})^\gamma) & ((b_{22})^o,(b_{22})^\alpha,(b_{22})^\beta,(b_{22})^\gamma) & \cdots & ((b_{2p})^o,(b_{2p})^\alpha,(b_{2p})^\beta,(b_{2p})^\gamma) \\ \vdots & \vdots & \cdots & \vdots \\ ((b_{p1})^o,(b_{p1})^\alpha,(b_{p1})^\beta,(b_{p1})^\gamma) & ((b_{p2})^o,(b_{p2})^\alpha,(b_{p2})^\beta,(b_{p2})^\gamma) & \cdots & ((b_{pp})^o,(b_{pp})^\alpha,(b_{pp})^\beta,(b_{pp})^\gamma) \end{bmatrix} \end{array} \tag{24}$$

or:

$$\tilde{A}_R^2 = \begin{array}{c} \\ c_1 \\ c_2 \\ \vdots \\ c_p \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \dots & c_p \end{array} \\ \begin{bmatrix} \tilde{b}_{11} & \tilde{b}_{12} & \dots & \tilde{b}_{1p} \\ \tilde{b}_{21} & \tilde{b}_{22} & \dots & \tilde{b}_{2p} \\ \vdots & \vdots & \dots & \vdots \\ \tilde{b}_{p1} & \tilde{b}_{p2} & \dots & \tilde{b}_{pp} \end{bmatrix} \end{array} \tag{25}$$

where:

$$(\tilde{b}_{ij})_j = \frac{\sum_{k=1}^{l} (w(vp)_k) \left[\left(\tilde{b}_{ij}^k \right)_j \right]}{\sum_{k=1}^{l} w(vp)_k} \tag{26}$$

At the third level, the fuzzy weighted collective pairwise comparison matrix of the IT investment risk sub-criteria with respect to the p IT investment risk criteria will be as follows:

$$\tilde{A}_R^3 = \begin{array}{c|cccc|} & sc_1 & sc_2 & \dots & sc_q \\ \hline sc_1 & ((d_{11})^o, (d_{11})^\alpha, (d_{11})^\beta, (d_{11})^\gamma)_p & ((d_{12})^o, (d_{12})^\alpha, (d_{12})^\beta, (d_{12})^\gamma)_p & \dots & ((d_{1q})^o, (d_{1q})^\alpha, (d_{1q})^\beta, (d_{1q})^\gamma)_p \\ sc_2 & ((d_{21})^o, (d_{21})^\alpha, (d_{21})^\beta, (d_{21})^\gamma)_p & ((d_{22})^o, (d_{22})^\alpha, (d_{22})^\beta, (d_{22})^\gamma)_p & \dots & ((d_{2q})^o, (d_{2q})^\alpha, (d_{2q})^\beta, (d_{2q})^\gamma) \\ \vdots & \vdots & \vdots & \dots & \vdots \\ sc_q & ((d_{q1})^o, (d_{q1})^\alpha, (d_{q1})^\beta, (d_{q1})^\gamma)_p & ((d_{q2})^o, (d_{q2})^\alpha, (d_{q2})^\beta, (d_{q2})^\gamma)_p & \dots & ((d_{qq})^o, (d_{qq})^\alpha, (d_{qq})^\beta, (d_{qq})^\gamma)_p \end{array} \tag{27}$$

or:

$$\tilde{A}_R^3 = \begin{array}{c} \\ sc_1 \\ sc_2 \\ \vdots \\ sc_q \end{array} \begin{array}{c} \begin{array}{cccc} sc_1 & sc_2 & \dots & sc_q \end{array} \\ \begin{bmatrix} (\tilde{d}_{11})_P & (\tilde{d}_{12})_P & \dots & (\tilde{d}_{1q})_P \\ (\tilde{d}_{21})_P & (\tilde{d}_{22})_P & \dots & (\tilde{d}_{2q})_P \\ \vdots & \vdots & \dots & \vdots \\ (\tilde{d}_{q1})_P & (\tilde{d}_{q2})_P & \dots & (\tilde{d}_{qq})_P \end{bmatrix} \end{array} \tag{28}$$

where:

$$(\tilde{d}_{ij})_j = \frac{\sum_{k=1}^{l} (w(vp)_k) \left[\left(\tilde{d}_{ij}^k \right)_p \right]}{\sum_{k=1}^{l} w(vp)_k} \tag{29}$$

At the fourth level, the fuzzy weighted collective pairwise comparison matrix of the n IT investment strategies with respect to the q IT investment risk sub-criteria will be as follows:

$$\tilde{A}_R^4 = \begin{array}{cc} & \begin{array}{cccc} a_1 & a_2 & \ldots & a_n \end{array} \\ \begin{array}{c} a_1 \\ a_2 \\ \vdots \\ a_n \end{array} & \left[\begin{array}{cccc} ((r_{11})^o,(r_{11})^\alpha,(r_{11})^\beta,(r_{11})^\gamma)_q & ((r_{12})^o,(r_{12})^\alpha,(r_{12})^\beta,(r_{12})^\gamma)_q & \ldots & ((r_{1n})^o,(r_{1n})^\alpha,(r_{1n})^\beta,(r_{1n})^\gamma)_q \\ ((r_{21})^o,(r_{21})^\alpha,(r_{21})^\beta,(r_{21})^\gamma)_q & ((r_{22})^o,(r_{22})^\alpha,(r_{22})^\beta,(r_{22})^\gamma)_q & \ldots & ((r_{2n})^o,(r_{2n})^\alpha,(r_{2n})^\beta,(r_{2n})^\gamma)_q \\ \vdots & \vdots & \ldots & \vdots \\ ((r_{n1})^o,(r_{n1})^\alpha,(r_{n1})^\beta,(r_{n1})^\gamma)_q & ((r_{n2})^o,(r_{n2})^\alpha,(r_{n2})^\beta,(r_{n2})^\gamma)_q & \ldots & ((r_{nn})^o,(r_{nn})^\alpha,(r_{nn})^\beta,(r_{nn})^\gamma)_q \end{array}\right] \end{array} \tag{30}$$

or:

$$\tilde{A}^4 = \begin{array}{cc} & \begin{array}{cccc} a_1 & a_2 & \ldots & a_n \end{array} \\ \begin{array}{c} a_1 \\ a_2 \\ \vdots \\ a_n \end{array} & \left[\begin{array}{cccc} (\tilde{r}_{11})_q & (\tilde{r}_{12})_q & \ldots & (\tilde{r}_{1n})_q \\ (\tilde{r}_{21})_q & (\tilde{r}_{22})_q & \ldots & (\tilde{r}_{2n})_q \\ \vdots & \vdots & \ldots & \vdots \\ (\tilde{r}_{n1})_q & (\tilde{r}_{n2})_q & \ldots & (\tilde{r}_{nn})_q \end{array}\right] \end{array} \tag{31}$$

where:

$$\tilde{r}_{ij} = \frac{\sum_{k=1}^{l} (w(vp)_k)\left(\tilde{r}_{ij}^k\right)}{\sum_{k=1}^{l} w(vp)_k} \tag{32}$$

Step 4.4: computation of the vector of the risk value for the IT investment strategies. The fuzzy composite vector of the deferrable IT investment strategies at the fourth level will be calculated based on the corresponding eigenvectors:

$$\underline{FRV} = \tilde{A}^4 \cdot \tilde{A}^3 \cdot \underline{\tilde{W}_R^2} = [\, FRV_1 \quad FRV_2 \quad \ldots \quad FRV_n \,]^T \tag{33}$$

or:

$$\underline{FRV} = [((FRV)^o, (FRV)^\alpha, (FRV)^\beta, (FRV)^\gamma)_{R_1}$$

$$((FRV)^o, (FRV)^\alpha, (FRV)^\beta, (FRV)^\gamma)_{R_2} \quad \ldots \; ((FRV)^o, (FRV)^\alpha, (FRV)^\beta, (FRV)^\gamma)_{R_n})]^T \tag{34}$$

where:

$$\tilde{A}_4 = \lfloor \underline{\tilde{W}_{R_1}^4} \quad \underline{\tilde{W}_{R_2}^4} \quad \ldots \quad \underline{\tilde{W}_{R_q}^4} \rfloor \tag{35}$$

$$\tilde{A}^3 = \lfloor \underline{\tilde{W}_{R_1}^3} \quad \underline{\tilde{W}_{R_2}^3} \quad \ldots \quad \underline{\tilde{W}_{R_p}^3} \rfloor \tag{36}$$

$$\underline{\tilde{W}_R^2} = Lim \frac{\left(\tilde{A}_R^2\right)^\eta \cdot e}{e^T \cdot \left(\tilde{A}_R^2\right)^\eta \cdot e} \quad \eta \rightarrow \infty \tag{37}$$

$$\underline{\tilde{W}}^{3}_{R_p} = Lim \frac{\left(\tilde{A}^{3}_{R}\right)^{\eta} \cdot e}{e^{T} \cdot \left(\tilde{A}^{3}_{R}\right)^{\eta} \cdot e} \quad \eta \rightarrow \infty \tag{38}$$

$$\underline{\tilde{W}}^{4}_{R_q} = Lim \frac{\left(\tilde{A}^{4}_{R}\right)^{\eta} \cdot e}{e^{T} \cdot \left(\tilde{A}^{4}_{R}\right)^{\eta} \cdot e} \quad \eta \rightarrow \infty \tag{39}$$

$$e = (1 \quad 1 \quad \ldots \quad 1)^{T} \tag{40}$$

Phase 5: development of the strategic IT investment plan

Decision makers also must consider the interaction between the real option and the investment risks. Therefore, in this phase, the IT investment strategy with the most value is determined in terms of real option and risk values in Phases 2 and 3. For this purpose, they are considered as the coefficients of the objective functions in the following fuzzy preemptive goal programming model with a series of applicable constraints. This phase is divided into the following three steps.

Step 5.1: determination of the goal and priority levels. The goals in the fuzzy preemptive goal programming model can be written as follows:

For the first priority level, there are two goals. These goals are equally important so they can have the same weight:

$$\begin{aligned} Max\ \ Z_1 = {} & E[FROV_1(T_1)] \cdot x_{11} + E[FROV_1(T_2)] \cdot x_{12} + \cdots + E[FROV_1(T_m)] \cdot x_{1m} + \\ & E[FROV_2(T_1)] \cdot x_{21} + E[FROV_2(T_2)] \cdot x_{22} + \cdots + E[FROV_2(T_m)] \cdot x_{2m} + \\ & \vdots \\ & E[FROV_n(T_1)] \cdot x_{n1} + E[FROV_n(T_2)] \cdot x_{n2} + \cdots + E[FROV_n(T_m)] \cdot x_{nm} \end{aligned}$$

$$\begin{aligned} Min\ \ Z_2 = {} & E(FRV_1) \cdot (x_{11} + x_{12} + \cdots + x_{1m}) + E(FRV_2) \cdot (x_{21} + x_{22} + \cdots + x_{2m}) + \\ & \cdots + E(FRV_n) \cdot (x_{n1} + x_{n2} + \cdots + x_{nm}) \end{aligned}$$

For the second priority level, we have:

$$\begin{gathered} f_1(x_{11}, x_{12}, \ldots, x_{nm}) \leq 0 \\ f_2(x_{11}, x_{12}, \ldots, x_{nm}) \leq 0 \\ \vdots \\ f_r(x_{11}, x_{12}, \ldots, x_{nm}) \leq 0 \\ x_i = 0, 1 \ \ (i = 1, 2, \ldots, n) \end{gathered}$$

$$\begin{aligned}Max\,Z_1 = {} & E[FROV_1(T_1)]\cdot x_{11} + E[FROV_1(T_2)]\cdot x_{12} + \cdots + E[FROV_1(T_m)]\cdot x_{1m} + \\ & E[FROV_2(T_1)]\cdot x_{21} + E[FROV_2(T_2)]\cdot x_{22} + \cdots + E[FROV_2(T_m)]\cdot x_{2m} + \\ & \vdots \\ & E[FROV_n(T_1)]\cdot x_{n1} + E[FROV_n(T_2)]\cdot x_{n2} + \cdots + E[FROV_n(T_m)]\cdot x_{nm}\end{aligned}$$

$$\begin{aligned}Min\ \ Z_2 = {} & E(FRV_1)\cdot(x_{11} + x_{12} + \cdots + x_{1m}) + E(FRV_2)\cdot(x_{21} + x_{22} + \\ & \cdots + x_{2m}) + \cdots + E(FRV_n)\cdot(x_{n1} + x_{n2} + \cdots + x_{nm})\end{aligned}$$

Subject to: (Model *P*)

$$\begin{aligned}x_{11} + x_{12} + \cdots + x_{1m} &\leq 1 \\ x_{21} + x_{22} + \cdots + x_{2m} &\leq 1 \\ &\vdots \\ x_{n1} + x_{n2} + \cdots + x_{nm} &\leq 1\end{aligned}$$

$$\begin{aligned}f_1(x_{11}, x_{12}, \ldots, x_{nm}) &\leq 0 \\ f_2(x_{11}, x_{12}, \ldots, x_{nm}) &\leq 0 \\ &\vdots \\ f_r(x_{11}, x_{12}, \ldots, x_{nm}) &\leq 0\end{aligned}$$

$$x_{ij} = 0, 1 \quad (i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m)$$

where $f_i(x_1, x_2, \ldots, x_n)$ are given functions of the n investments.

Step 5.2: computation of the goal values. In this step, instead of trying to optimize each objective function, the strategic IT investment board will specify a realistic goal or target value that is the most desirable value for that function.

Step 5.3: construction of the proposed goal programming model. The first objective function is to be maximized and the second objective function is to be minimized. Therefore, the proposed fuzzy goal programming model for the above two-objective strategic IT investment decision will be the following single-objective model:

$$Min\ \ D = P_1\left(s_1^+ + s_2^-\right) + P_2 s_3^- + \cdots + P_{r+2} s_r^-$$

Subject to: (Model F)

$$\begin{aligned}& E[FROV_1(T_1)]\cdot x_{11} + E[FROV_1(T_2)]\cdot x_{12} + \cdots + E[FROV_1(T_m)]\cdot x_{1m} + \\ & E[FROV_2(T_1)]\cdot x_{21} + E[FROV_2(T_2)]\cdot x_{22} + \cdots + E[FROV_2(T_m)]\cdot x_{2m} + \\ & \vdots \\ & E[FROV_n(T_1)]\cdot x_{n1} + E[FROV_n(T_2)]\cdot x_{n2} + \cdots + E[FROV_n(T_m)]\cdot x_{nm}\end{aligned}$$

$$S_1^- - S_1^+ = l_1$$

$$
\begin{aligned}
&E(FRV_1)\cdot(x_{11}+x_{12}+\cdots+x_{1m})+E(FRV_2)\cdot(x_{21}+x_{22}+\\
&\quad\cdots+x_{2m})+\cdots+E(FRV_n)\cdot(x_{n1}+x_{n2}+\cdots+x_{nm})+s_2^- - s_2^+ = u_1
\end{aligned}
$$

$$f_1(x_{11}, x_{12}, \ldots, x_{nm}) + s_3^+ + s_3^+ = 0$$

$$f_2(x_{11}, x_{12}, \ldots, x_{nm}) + s_4^+ + s_4^- = 0$$

$$\vdots$$

$$f_r(x_{11}, x_{12}, \ldots, x_{nm}) + s_{r+2}^+ + s_{r+2}^- = 0$$

$$x_{11} + x_{12} + \cdots + x_{1m} \leq 1$$

$$x_{21} + x_{22} + \cdots + x_{2m} \leq 1$$

$$\vdots$$

$$x_{n1} + x_{n2} + \cdots + x_{nm} \leq 1$$

$$x_{ij} = 0, 1 \quad (i = 1, 2, \ldots, n;\ j = 1, 2, \ldots, m)$$

$$s_h^+, s_h^- \geq 0 \quad (h = 1, 2, \ldots, r + 2)$$

$$s_h^+ \cdot s_h^- = 0$$

The optimal solution for model (*F*) is the deferrable IT investment strategy with the most values at the time T_i. Next, we present a numerical example to demonstrate the implementation process of this framework.

3. Case study

We implemented the proposed model at Mornet[1], a large mortgage company in the city of Philadelphia with an urgent need to select an optimal IT investment strategy for their deferrable investment opportunities.

In Phase 1, the chief executive officer instituted a committee of four strategic IT investment board members, including:

- $(ITIB)_1$. The chief operating officer.
- $(ITIB)_2$. The chief information officer.
- $(ITIB)_3$. The heads of the business unit.
- $(ITIB)_4$. The chief financial officer.

In Phase 2, the investment board identifies five different types of deferrable investment opportunities with the following characteristics (Table I) as suggested by Carlsson *et al.* (2007):

- a_1. Project 1 has a large negative estimated NPV (due to huge uncertainties) and can be deferred up to two years ($v(FNPV) < 0,\ T = 2$).
- a_2. Project 2 includes positive NPV with low risks and has no deferral flexibility ($v(FNPV) > 0,\ T = 0$).

a_3. Project 3 has revenues with large upward potentials and managerial flexibility, but its "reserve costs" (c) are very high.

a_4. Project 4 requires a large capital expenditure once it has been undertaken and has a deferral flexibility of a maximum of one year.

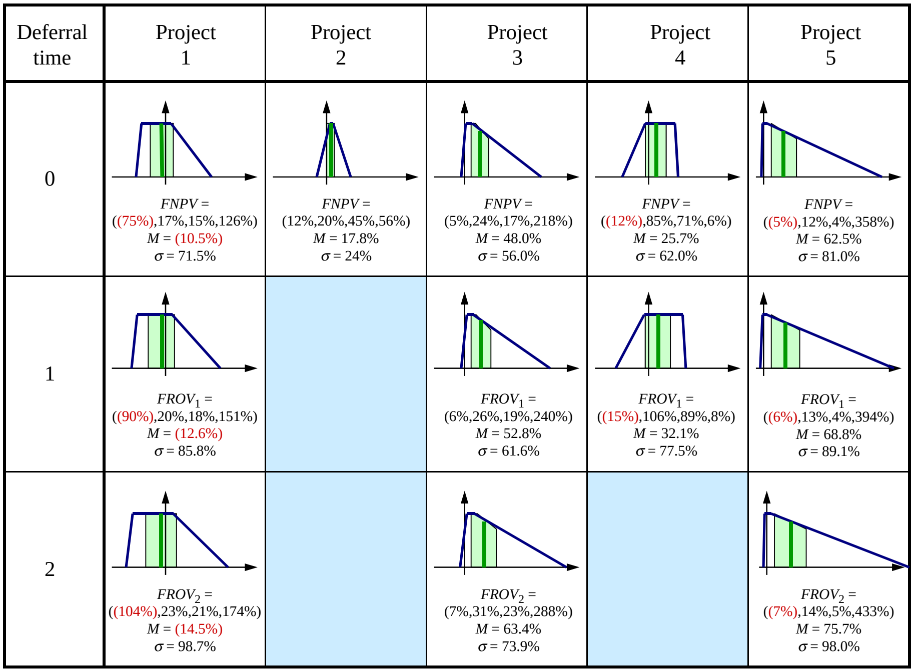
a_5. Project 5 represents a small flexible project with low revenues, but it opens the possibility of further projects that are much more profitable.

In Phase 3, the fuzzy real option values of the five different deferrable investment opportunities shown in Figure 2 were determined for years 1 and 2.

In Phase 4, the strategic IT investment board determined the GFAHP three criteria of firm-specific risks, development risks and external environment risks as suggested by Benaroch (2002). The firm-specific risks were further divided into four sub-criteria: organizational risks, user risks, requirement risks and structural risks.

Table I.
The five deferrable IT investment opportunities

Deferral time	Project 1	Project 2	Project 3	Project 4	Project 5
0	$FNPV = ((75\%), 17\%, 15\%, 126\%)$	$FNPV = (12\%, 20\%, 45\%, 56\%)$	$FNPV = (5\%, 24\%, 17\%, 218\%)$	$FNPV = ((12\%), 85\%, 71\%, 6\%)$	$FNPV = ((5\%), 12\%, 4\%, 358\%)$
1	✓		✓	✓	✓
2	✓		✓		✓



Deferral time	Project 1	Project 2	Project 3	Project 4	Project 5
0	$FNPV$ = ((75%),17%,15%,126%) M = (10.5%) σ = 71.5%	$FNPV$ = (12%,20%,45%,56%) M = 17.8% σ = 24%	$FNPV$ = (5%,24%,17%,218%) M = 48.0% σ = 56.0%	$FNPV$ = ((12%),85%,71%,6%) M = 25.7% σ = 62.0%	$FNPV$ = ((5%),12%,4%,358%) M = 62.5% σ = 81.0%
1	$FROV_1$ = ((90%),20%,18%,151%) M = (12.6%) σ = 85.8%		$FROV_1$ = (6%,26%,19%,240%) M = 52.8% σ = 61.6%	$FROV_1$ = ((15%),106%,89%,8%) M = 32.1% σ = 77.5%	$FROV_1$ = ((6%),13%,4%,394%) M = 68.8% σ = 89.1%
2	$FROV_2$ = ((104%),23%,21%,174%) M = (14.5%) σ = 98.7%		$FROV_2$ = (7%,31%,23%,288%) M = 63.4% σ = 73.9%		$FROV_2$ = ((7%),14%,5%,433%) M = 75.7% σ = 98.0%

Figure 2.
The fuzzy real option values of the five deferrable IT investment opportunities

The development risks were further divided into two sub-criteria: team risks and complexity risks. External environment risks were further divided into two sub-criteria: competition risks and market risks.

Next, the possibilistic mean risk values of the investment opportunities presented in Table II were calculated.

In Phase 5, assuming a per annum investment, the deferrable IT investment strategy with the most value was determined using the following two-objective decision-making model:

$$\begin{aligned} Min\ \ Z_2 = {} & 0.45(x_{10} + x_{11} + x_{12}) + 0.1x_{20} + 0.35(x_{30} + x_{31} + x_{32}) + 0.15(x_{40} + x_{41}) \\ & + 0.05(x_{50} + x_{51} + x_{52}) \end{aligned}$$

Subject to: (Model P)

$$x_{10} + x_{11} + x_{12} \leq 1$$

$$x_{21} \leq 1$$

$$x_{30} + x_{31} + x_{32} \leq 1$$

$$x_{40} + x_{41} \leq 1$$

$$x_{50} + x_{51} + x_{52} \leq 1$$

$$x_{10} + x_{20} + x_{30} + x_{40} + x_{50} \leq 1$$

$$x_{11} + x_{31} + x_{41} + x_{51} \leq 1$$

$$x_{12} + x_{32} + x_{52} \leq 1$$

$$x_{10}, x_{11}, x_{12}, x_{20}, x_{30}, x_{31}, x_{32}, x_{40}, x_{41}, x_{50}, x_{51}, x_{52} = 0, 1$$

Therefore, the goal programming model for the above two-objective strategic IT investment decision will be the following single objective model:

$$Min\ \ D = P_1 \cdot \left(s_1^- + s_2^+\right)$$

Subject to: (Model F)

$$\begin{aligned} & (-0.105)x_{10} + (-0.126) \cdot x_{11} + (-0.145) \cdot x_{12} + 0.178x_{20} + 0.48x_{30} + 0.528x_{31} \\ & \quad + 0.634x_{32} + 0.257x_{40} + 0.321x_{41} + 0.625x_{50} + 0.688x_{51} + 0.757x_{52} \\ & \quad + \left(s_1^- - s_1^+\right) = 1.5 \end{aligned}$$

$$\begin{aligned} & 0.45(x_{10} + x_{11} + x_{12}) + 0.1x_{20} + 0.35(x_{30} + x_{31} + x_{32}) + 0.15(x_{40} + x_{41}) \\ & \quad + 0.05(x_{50} + x_{51} + x_{52}) + \left(s_2^- - s_2^+\right) = 0.6 \end{aligned}$$

$$x_{10} + x_{11} + x_{12} \leq 1$$

$$x_{20} \leq 1$$

Project 1	Project 2	Project 3	Project 4	Project 5
$E(FRV_1) = 0.45$	$E(FRV_2) = 0.10$	$E(FRV_3) = 0.35$	$E(FRV_4) = 0.15$	$E(FRV_5) = 0.05$

Table II. The possibilistic mean risk value of the IT investment opportunities

$$x_{30} + x_{31} + x_{32} \leq 1$$

$$x_{40} + x_{41} \leq 1$$

$$x_{50} + x_{51} + x_{52} \leq 1$$

$$x_{10} + x_{20} + x_{30} + x_{40} + x_{50} \leq 1$$

$$x_{11} + x_{31} + x_{41} + x_{51} \leq 1$$

$$x_{12} + x_{32} + x_{52} \leq 1$$

$$x_{10}, x_{11}, x_{12}, x_{20}, x_{30}, x_{31}, x_{32}, x_{40}, x_{41}, x_{50}, x_{51}, x_{52} = 0, 1$$

$$s_1^+, s_1^-, s_2^+, s_2^- \geq 0$$

$$s_1^+ \cdot s_1^- = 0$$

$$s_2^+ \cdot s_2^- = 0$$

The optimal solution for model (*F*) given in Table III shows Projects 1 and 2 were rejected. Project 3 was approved for to start immediately, Project 4 was approved to start next year and Project 5 was approved to start in two years.

4. Discussion and practical perspectives

It is hard to say for sure which IT investment strategy is the best, but, we can make the selection process more comprehensive and systematic. The group decision process used at Mornet was intended to enhance decision making and promote consensus. Our four investment board members were highly educated; three of them held graduate degrees in business and one of them held a doctorate in economics. To this end, a more logical and persuasive multi-criteria decision-making method was necessary to gain their confidence and support. Although our board members were educated and creative, their managerial judgment and intuition was limited by background and experience. One manager lacked strategic management skills while another had limited experience in banking. Upon completion of the IT investment strategy selection process, we held a meeting with the board to discuss the results and finalize our recommendation. The four board members unanimously agreed that the proposed framework provided invaluable analysis aids and information processing support. They were convinced that the result was unbiased and consistent.

Armed with this feedback, we were confident that we could sell our recommendation to the top management. Nevertheless, we were all aware that consensus building at Mornet was a gradual process and could not be achieved overnight. We knew that building internal alliances and selecting an IT investment strategy that could cut across different functional areas was a difficult task. The board members agreed to target various groups and key people at Mornet in order to gain their support. They began

Table III.
The optimal solution for model (F)

Deferral time	Project 1	Project 2	Project 3	Project 4	Project 5
0			✓		
1				✓	
2					✓

building internal alliances with functional units and focused their efforts on getting other line managers on board. This process involved fostering collaboration and avoiding alienation of potential internal allies. The board also decided to get the line managers on board. Gaining the line management support resulted in the dedication of some line budget to the implementation process. This led to a virtuous circle since the fact that some line mangers agreed to pay for some of the implementation expenses increased their commitment. This encouraged other line managers to jump on the bandwagon and participate in the selection process.

The internal alliance building process would not be complete without top management support. Our board was adamant about the importance of gaining support from the top management. Gaining the top management support was easier than it may seem from the outside. The board members had already built internal alliances and support of various key people and line managers. We discussed the overwhelming internal support and the tangible and intangible benefits of our IT investment strategy with the top management who in turn agreed to implement our recommendation. We were also required to develop a long-term plan to measure the IT investment selection success through qualitative and quantitative measures.

The analysis of this case study allows the articulation of a series of key factors that can be considered as important in contributing to the successful selection and implementation of IT investment strategies. The first is building internal alliances. The second element is getting the line managers on board. The third factor is the full and continual support given by top management. The fourth key ingredient is the persistent and systematic processes in place to measure the IT investment success.

5. Conclusions and future research directions

IT investments represent the largest capital expenditure items for many organizations and have a tremendous impact on productivity by reducing costs, improving quality and increasing value to customers. As a result, many organizations continue to invest large sums of money in IT in anticipation of a material return on their investment. The selection of appropriate IT investments has been one of the most significant business challenges of the last decade.

In this paper, we proposed a novel two-dimensional approach that determined the deferrable strategy with the most value by maximizing the real option values while minimizing the risks associated with each alternative strategy. First, the deferrable investment strategies were prioritized according to their values using the ROA. Then, the risks associated with each investment strategy were quantified using the GFAHP. Finally, the values associated with the two dimensions were integrated to determine the deferrable IT investment strategy with the most value using a fuzzy preemptive goal programming model. This framework can be easily generalized to N-dimensional problems. We have developed a framework that can be used to evaluate IT investments based on the real option concept. This approach incorporates the linkage among economic value, real option value and IT investments that could lead to a better-structured decision process.

The proposed approach provides guidelines for managing IT investment projects. Managers face the difficulty that most IT investment projects are inherently risky, especially in a rapidly changing business environment. Over the past several years, increasingly sophisticated analytical techniques have been developed for selecting the IT investments, but not implemented within organizations. Our approach provides a simple, intuitive, generic and comprehensive investment management tool. The trapezoidal fuzzy numbers used in this study allows the proposed model to be implemented easily with the most commonly used spreadsheet software. Managers can easily understand how to implement the proposed approach to assess their technology portfolio requirements.

In contrast to the traditional ROA literature, our approach contributes to the literature by incorporating a risk dimension parameter. We emphasize the importance of categorizing risk management in IT investment projects since some risk cannot be eliminated. After estimating the possibility and severity of each risk factor, we obtain an overall risk level for each IT investment under consideration. This assumes by implication that all risk factors are independent. However, in practice, there may be some interaction between different risk factors and their influence on the expected payoffs could be not independent. Future research considering correlation coefficients between risk factors is rather challenging but necessary to gain insight into this interaction influence in the application of ROA to IT investment decisions.

We have developed a framework that can be used to evaluate IT investment strategies based on the real option concept. This approach incorporates the linkage among economic value, real option value and IT investments that could lead to a better-structured decision process. The overall contributions of the novel framework proposed in this study are threefold:

(1) Our framework addresses the gaps in the IT investment planning literature on the effective and efficient assessment of IT investment opportunities.

(2) Our framework provides a comprehensive and systematic framework that combines ROA with a fuzzy group multi-criteria approach to assess IT investment strategies.

(3) Current IT investment assessment models are somewhat limited in their ability to come to grips with issues of inference and fuzziness. Our framework considers fuzzy logic and fuzzy sets to represent ambiguous, uncertain or imprecise information in the It investment evaluation process.

Future research considering correlation coefficients between the risk and benefit factors is rather challenging but necessary to gain insight into this interaction influence in the application of ROA to strategic IT investment decision in organizations. Another possible future research direction is to investigate other drivers that influence the IT investment decisions. These value drivers could also be incorporated into the model proposed in this study.

Note

1. The name is changed to protect the anonymity of the company.

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Further reading

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Appendix. The mathematical notations

Let us introduce the following mathematical notations and definitions used throughout this paper:

c_j	The *j*th criterion.
a_i	The *i*th IT investment strategy.
p	The number of IT investment risk criteria.
q	The number of IT investment risk sub-criteria.
l	The number of IT investment board members.
n	The number of alternative IT investment strategies.
T_{i}	The time to maturity of the *i*th IT investment strategy.
T_m	The maximum deferral time of the IT investments.
T_1	The minimum deferral time of the IT investments.

r_i	The risk-free interest rate.
$w(vp)_K$	The voting power of the IT investment board member $(ITIB)_k$ ($K = 1,2,\ldots, l$).
$\tilde{B}_i^k(T_j)$	The individual fuzzy present value of the expected cash flows of the ith IT investment strategy at time T_j evaluated by strategic IT investment board member $(ITIB)_k$.
$\tilde{B}_i(T_j)$	The weighted collective fuzzy present value of the expected cash flows of the ith IT investment strategy at time T_j.
$E(\tilde{B}_i(T_j))$	The possibilistic mean value of the weighted collective present value of expected cash flows of the ith IT investment strategy at time T_j.
$\tilde{C}_i^k(T_j)$	The individual fuzzy present value of the expected cost of the ith IT investment strategy at time T_j evaluated by strategic IT investment board member $(ITIB)_k$.
$\tilde{C}_i(T_j)$	The weighted collective fuzzy present value of the expected cost of the ith IT investment strategy at time T_j.
$E(\tilde{C}_i(T_j))$	The possibilistic mean value of the weighted collective expected costs of the ith IT investment strategy at time T_j.
δ_i	The value loss over the duration of the option.
$(\sigma^2(T_j))_i$	The variance of the weighted collective fuzzy present value of expected cash flows of the ith IT investment strategy at time Tj evaluated by strategic IT investment board member $(ITIB)_k$.
$N(D_{1i}(T_j))$	The IT investment strategy ith cumulative normal probability for the D_1.
$N(D_{2i}(T_j))$	The IT investment strategy ith cumulative normal probability for the D_2.
$\tilde{b}_{ij}^k$	The individual fuzzy comparison qualification between criterion i with criterion j evaluated by strategic IT investment board member $(ITIB)_k$.
$\left(\tilde{d}_{ij}^k\right)_p$	The individual fuzzy comparison qualification between sub-criterion i with sub-criterion j with respect to criterion p evaluated by strategic IT investment board member $(ITIB)_k$.
$\left(\tilde{r}_{ij}^k\right)_q$	The individual fuzzy comparison qualification between IT investment strategy i with IT investment strategy j with respect to sub-criterion q evaluated by strategic IT investment board member $(ITIB)_k$.
$\tilde{b}_{ij}$	The weighted fuzzy collective comparison qualification between criterion i with criterion j.
$(\tilde{d}_{ij})_j$	The weighted fuzzy collective comparison qualification between sub-criterion i with sub-criterion j with respect to criterion j.
$(\tilde{r}_{ij})_j$	The weighted fuzzy collective comparison qualification between IT investment strategy i with IT investment strategy j with respect to sub-criterion j.
s_h^+	The amount by which we numerically exceed the hth goal.
s_h^-	The amount by which we numerically fall short of the hth goal.
$\left(\tilde{A}_R^2\right)^K$	The individual fuzzy pairwise comparison matrix of p criteria of IT investment risk evaluated by strategic IT investment board member $(ITIB)_k$.

$\left(\tilde{A}_R^3\right)^K$	The individual fuzzy pairwise comparison matrix of IT investment risk sub-criteria with respect to the *p* IT investment risk criteria evaluated by strategic IT investment board member $(ITIB)_k$.
$\left(\tilde{A}_R^4\right)^K$	The individual fuzzy pairwise comparison matrix of *n* IT investment strategies with respect to the *q* IT investment risk sub-criteria evaluated by strategic IT investment board member $(ITIB)_k$.
$\left(\tilde{A}_R^2\right)$	The weighted fuzzy collective pairwise comparison matrix of the *p* IT investment risk criteria.
$\left(\tilde{A}_R^3\right)$	The weighted fuzzy collective pairwise comparison matrix of IT investment risk sub-criteria with respect to the *p* IT investment risk criteria.
$\left(\tilde{A}_R^4\right)$	The weighted fuzzy collective pairwise comparison matrix of the *n* IT investment strategies with respect to the *q* IT investment risk sub-criteria.
$\left(\tilde{A}_R^2\right)^K$	The weighted fuzzy collective IT investment risk matrix evaluated by strategic IT investment board member $(ITIB)_k$.
$FROV_i(T_j)$	The fuzzy real option value of the *i*th IT investment strategy at time T_j.
FRV_i	The fuzzy risk value of the *i*th IT investment strategy.
$\tilde{A}_{FROV}$	The fuzzy real option value matrix of the deferrable IT investment strategies.
$\underline{FRV}$	The fuzzy risk value vector of the IT investment strategies.

About the authors

Faramak Zandi is an Assistant Professor of Information Systems and Chairman of the Industrial Engineering Department at Alzahra University in Iran. He holds a PhD in Industrial Engineering. His research interests include IT, enterprise architectures, decision making, quality management systems and transportation planning. He has published in the *International Journal of Business Information Systems*, *International Journal of Mathematics in Operational Research*, *International Journal of Information Technology and Management*, *IEEE Computer Society*, *Journal of Tehran University* and *Amirkabir Journal of Science & Technology* and *Quarterly Journal of Educational Innovations*.

Madjid Tavana is a Professor of Management Information Systems and Decision Sciences and the Lindback Distinguished Chair of Information Systems at La Salle University where he served as Chairman of the Management Department and Director of the Center for Technology and Management. He has been a distinguished Faculty Fellow at NASA's Kennedy Space Center, NASA's Johnson Space Center, Naval Research Laboratory – Stennis Space Center and Air Force Research Laboratory. He was awarded the prestigious Space Act Award by NASA. He holds an MBA, a PMIS and a PhD in Management Information Systems. He received his Post-doctoral Diploma in strategic information systems from the Wharton School of the University of Pennsylvania. He is the Editor-in-Chief for the *International Journal of Strategic Decision Sciences*, *The International Journal of Enterprise Information Systems* and *The International Journal of Applied Decision Sciences*. He has published in journals such as *Decision Sciences*, *Interfaces*, *Information Systems*, *Information and Management*, *Computers and Operations Research*, *Journal of the Operational Research Society* and *Advances in Engineering Software*, among others. Madjid Tavana is the corresponding author and can be contacted at: tavana@lasalle.edu

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