A multi-attribute group decision support system for information technology project selection

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Abstract: The increasing intensity of global competition and the rapid advances in information technology (IT) have led organisations to search for more efficient and effective ways to manage their business. With the rapid growth of IT and global complexity, selecting information system projects that further business objectives has become a complex task. This complexity is due to a larger number of alternatives, multiple and often conflicting attributes, and an increasingly turbulent business environment. Traditional assessment techniques overemphasise quantitative and economic analysis and often neglect to consider qualitative and non-economic factors in the formal selection process. Furthermore, prior research for IT project selection does not consider interdependencies among candidate projects. In this paper, a comprehensive multi-attribute decision-making (MADM) approach for IT project selection is proposed. This decision model is illustrated by a case study of enterprise information system project selection at a textile manufacturer in Philadelphia. The proposed approach considers both quantitative and qualitative attributes as well as the interdependencies among candidate projects in a hybrid model that integrates the technique for order preference by similarity to ideal solution (TOPSIS) with multi-objective decision-making (MODM). MADM is used for the sorting or the ranking of the IT projects according to multiple attributes, and MODM is used for driving a vector optimisation-based solution.

Keywords: technique for order preference by similarity to ideal solution; TOPSIS; multi-attribute decision-making; MADM; preference aggregation; distance function; multi-objective decision-making; MODM; information technology; project selection.

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1 Introduction

In most project evaluation problems, several conflicting objectives must be satisfied simultaneously to obtain an optimal solution. The evaluation procedure can be difficult because complex problems typically involve many qualitative and quantitative attributes (Kahraman and Çebi, 2009). A large body of intuitive and analytical models has evolved over the last several decades to assist decision makers (DMs) in project evaluation. While these models have made great strides in project evaluation, the intuitive models lack a structured framework and the analytical models do not capture intuitive preferences. This paper proposes a hybrid multi-attribute decision-making (MADM) and multi-objective decision-making (MODM) model that considers the multi-dimensional nature of project evaluation problems. In the MADM context, a preference relation is constructed; then, the derived priority vector is used to rank various alternatives (Wu, 2009). In the MODM context, these rankings are used to derive a vector optimisation-based solution (Alves and Climaco, 2004). Combining MADM and MODM supports both qualitative and quantitative decision attributes, as well as the interdependencies among the projects. The proposed methodology allows for the rational and consistent aggregation of subjective and objective judgements.

2 Literature review and background

The literature on project selection contains hundreds of models, including scoring methods, economic methods, portfolio methods and decision analysis. Scoring methods use algebraic formulas to produce an overall score for each project (Moore and Baker, 1969; Cooper, 1992; Osawa and Murakami, 2002; Osawa, 2003). Economic methods use financial models to calculate the monetary payoff of each project (Graves and Ringuest, 1991; Mehrez, 1988). Portfolio methods evaluate the entire set of projects to identify the most attractive subset (Cooper et al., 1999; Girotra et al., 2007; Lootsma et al., 1990; Mojsilovi et al., 2007; Vepsalainen and Lauro, 1988; Wang and Hwang, 2007). Cluster analysis, a more specific form of portfolio analysis, groups projects according to their support of the strategic positioning of the firm (Mathieu and Gibson, 1993). Decision-analysis models compare various projects according to their expected value (Hazelrigg and Huband, 1985; Thomas, 1985). Finally, simulation, a special form of decision analysis, uses random numbers and simulation to generate a large number of problems and pick the best outcome (Abacoumkin and Ballis, 2004; Mandakovic and Souder, 1985; Paisittanand and Olson, 2006).

Most of these models have been used to evaluate research and development projects (Coffin and Taylor, 1996; Girotra et al., 2007; Osawa and Murakami, 2002; Osawa, 2003, Taylor et al., 1982; Wang and Hwang, 2007; Weber et al., 1990), information systems projects (Mojsilovi et al., 2007; Paisittanand and Olson, 2006; Santhanam and Kyparisis, 1995; Santhanam et al., 1989; Schniederjans and Santhanam, 1993) and capital budgeting projects (Graves and Ringuest, 1991; Mehrez, 1988).

Recently, researchers working on project evaluation and selection have focused on MADM models to integrate the intuitive preferences of multiple DMs into structured and analytical frameworks (Bailey et al., 2003; Costa et al., 2003; Dominic et al., 2008; Hsieh et al., 2004; Liesiö et al., 2007; Tavana 2006). MADM methods can be classified by the type of information used: methods based on quantitative measurements, qualitative measurements converted to quantitative variables, qualitative measurements not converted to quantitative variables, and comparative preference using pairwise comparison.

Methods based on quantitative measurements include the technique for order preference by similarity to ideal solution (TOPSIS) (Hwang and Yoon, 1981; Shih, 2008), simple additive weighting (SAW) (Chou et al., 2008; Zavadskas et al., 2007), linear programming techniques for multidimensional analysis of preference (LINMAP) (Sirinivasan and Shocker, 1973; Xia et al., 2006) and COmplex PRoportional assessment (COPRAS) (Kaklauskas et al., 2006; Zavadskas et al., 2008). Methods based on qualitative measurements include two widely known groups of methods, the analytic hierarchy process (AHP) (Saaty, 1994) and fuzzy set theory methods (Zimmermann, 2000).

Methods based on qualitative measurements not converted to quantitative variables include methods of verbal decision analysis (Berkeley et al., 1991; Andre'eva et al., 1995; Larichev, 1992; Larichev et al., 1995; Larichev and Moshkovich, 1997; Flanders et al., 1998). Comparative preference methods based on pairwise comparison of alternatives include ELECTRE (Roy, 1996) and PROMETHEE I and II (Brans, et al., 1986; Diakoulaki and Koumoutsos, 1991).

Traditional assessment techniques overemphasise quantitative and economic analysis that often neglects to consider qualitative and non-economic factors in the formal selection process. Prior research in information technology (IT) project selection also does not consider interdependencies among candidate projects. In this paper, a comprehensive MADM-MODM approach for IT project selection is proposed. This approach considers both quantitative and qualitative attributes, as well as the interdependencies among candidate projects, in a hybrid model that integrates TOPSIS with MODM. MADM is used for the sorting or the ranking of the IT projects according to multiple attributes, and MODM is used for deriving a vector optimisation-based solution. This paper is organised into four sections. The next section presents the details of the MADM approach proposed in this study. In Section 4, a case study is presented to illustrate the implementation process of the IT project selection model, and Section 5 presents concluding remarks and future research directions.

3 The proposed framework

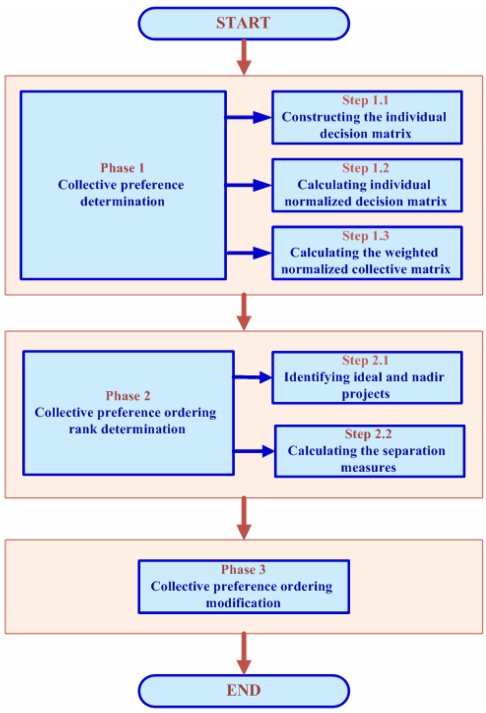
The framework in Figure 1 is proposed for selecting IT projects. This framework consists of three main phases:

1 determining the collective preference

2 ranking the collective preference ordering based on the ideal and nadir IT projects

3 modifying collective preference ordering.

Figure 1 The proposed it project selection framework (see online version for colours)



The parameters are defined as:

A^k the individual decision matrix

D^k the normalised individual decision matrix

F the weighted normalised collective decision matrix

C the collective decision matrix

C_{ij} the normalised collective value of project *i* for attribute *j*

Q_{ij} the group qualification of project r_i for attribute C_j

f_{ij} the weighted normalised collective value of project *i* for attribute *j*

$v(q)_k^j$ the voting power of DM O_k for scoring attribute C_j $(j = 1, 2, ..., p\ ,\ k = 1, 2, ..., l)$

a_{ij}^k the *j*-th attribute value of the *i*-th project evaluated by DM O_k

d_{ij}^k the normalised individual value of DM O_k for project *i* for attribute *j*

w_j^k the importance weight of attribute C_j by DM O_k

s_i^* the separation of project *i* from the ideal solution

s_i^- the separation of project *i* from the nadir solution

w_j the group weight of attribute *j*

r^* the most preferable project (ideal solution)

r^- the least preferable project (nadir solution)

J the set of benefit attributes

J' the set of cost attributes

C_j The *j*-th attribute

r_i the *i*-th project

p number of attributes

l number of DMs

n number of projects

Assuming that l DMs with equal voting power are selected to evaluate n projects, the proposed framework involves the following phases and steps:

Phase 1 Collective preference determination

Group decisions are usually understood as aggregating different individual preferences on a given set of IT projects to a single collective preference. This phase is divided into the following three steps:

Step 1.1 Constructing the individual decision matrix

The committee uses multiple attributes in ranking the IT projects. These attributes can be classified as either quantitative or qualitative which are judgmental and difficult to measure. Because of the differences in background, education and experience of the group members, this approach allows for assigning different voting power weights to individual DMs in addition to assigning different weights assigned to the attributes. Therefore, the vector of group weights is derived by synthesising the individual weights of the group members as follows:

$$W = [w_1, w_2, ..., w_j, ..., w_p] \tag{1}$$

where

$$w_j = \frac{\sum_{k=1}^{l} v(q)_j^k \cdot w_j^k}{\sum_{k=1}^{l} v(q)_j^k} \tag{2}$$

and we have

$$W^k = [w_1^k, w_2^k, ..., w_j^k, ..., w_p^k] \quad k = 1, 2, ..., l \tag{3}$$

$$V(q)^k = [v(q)_1^k, v(q)_2^k, ..., v(q)_j^k, ..., v(q)_p^k] \tag{4}$$

Most IT project evaluation problems need to be tackled collectively by a group of people rather than an individual DM. Choi et al. (1994) point out four properties of group decision problems which render them hard to attack:

1 they are social problems not mathematical ones

2 it is difficult to satisfy all constraints

3 they are more difficult to model than problems with single DM

4 there are few methodologies to verify fairness in the aggregation of the preferences.

In this study, the voting power $v(q)^k$, is calculated based on Borda's method (Brams, 1985; Truchon, 2008). Assuming that m projects are being evaluated by l DMs, who are using p attributes:

$$A^k = [a_{ij}] = \begin{array}{c} \\ r_1 \\ r_2 \\ \vdots \\ r_m \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \ldots & C_p \end{array} \\ \begin{bmatrix} a_{11}^k & a_{12}^k & \cdots & a_{1p}^k \\ a_{21}^k & a_{21}^k & \cdots & a_{2p}^k \\ \vdots & \vdots & \cdots & \vdots \\ a_{n1}^k & a_{n2}^k & \cdots & a_{np}^k \end{bmatrix} \end{array} \quad (k = 1, 2, ..., l) \tag{5}$$

The symbol $A_i^k = [a_{i1}, ..., a_{ip}]^k$ is the vector of valuations from DM k for project i according to the attributes 1 through p. In the proposed framework, the DMs consider a single attribute, and then rank the projects for that attribute.

Step 1.2 Calculating the individual normalised decision matrix

Each attribute could have a different unit of measurement. Therefore, it is necessary to transform the attribute scores into a set of comparable scales. Vector normalisation is employed so that all attributes are measured in dimensionless units. In particular, each column vector of the individual decision matrix is divided by its norm. Each normalised value d_{ij}^k of the individual normalised decision matrix A^k is calculated as:

$$d_{ij}^k = \frac{a_{ij}^k}{\sqrt{\sum_{i=1}^{m} (a_{ij}^k)^2}} \quad (j = 1, 2, ..., p;\ k = 1, 2, ...l) \tag{6}$$

Step 1.3 Calculating the weighted normalised collective matrix

In order to form a collective ordering of the individual preferences, for a given attribute, the a_{ij}^k values will be modified for scoring by the voting powers as follows:

$$Q_{ij} = \frac{\sum_{k=1}^{l} v(q)_j^k \cdot d_{ij}^k}{\sum_{k=1}^{l} v(q)_j^k} \tag{7}$$

The collective matrix C is defined as:

$$C = \begin{array}{c} \\ r_1 \\ r_2 \\ \vdots \\ r_n \end{array} \begin{array}{c} \begin{array}{cccc} C_1 & C_2 & \cdots & C_p \end{array} \\ \begin{bmatrix} Q_{11} & a_{12}^k & \cdots & Q_{1p} \\ Q_{21} & Q_{22} & \cdots & Q_{2p} \\ \vdots & \vdots & \cdots & \vdots \\ Q_{n1} & Q_{n2} & \cdots & Q_{np} \end{bmatrix} \end{array} \tag{8}$$

Next, the weighted normalised collective matrix can be calculated by multiplying each column of the matrix C with its associated weight w_j. Therefore, the weighted normalised collective matrix F is:

$$F = [f_{ij}] = [w_j \cdot Q_{ij}] \ (i = 1, ..., n \ ; \ j = 1, ..., p) \quad (9)$$

Phase 2 Collective preference ordering rank determination

Next, the collective preference ordering rankings are determined based on the ideal and nadir projects. Using TOPSIS, the chosen IT project should have the shortest distance from the ideal project which is composed of all the best attribute values attainable, and the farthest from the nadir project composed of all the worst attribute values attainable (Shih, 2008; Shih et al., 2007). Therefore, in the proposed approach, the group TOPSIS method is used for ranking the collective preference ordering.

Step 2.1 Identifying ideal and nadir projects

Let two sets of artificial projects r^* and r^- be defined as:

$$r^* = \{(\max_i c_{ij} \big/ j \in J), (\min_i c_{ij} \big/ j \in J')\} = \{c_1^*, ..., c_j^*, ... c_p^*\} \ (i = 1, 2, ..., n) \quad (10)$$

$$r^- = \{(\min_i c_{ij} \big/ j \in J), (\max_i c_{ij} \big/ j \in J')\} = \{c_1^-, ..., c_j^-, ... c_p^-\} \ (i = 1, 2, ..., n) \quad (11)$$

where

$$J = \{j = 1, 2, ..., p \ / \ j \ \textit{associated with benefit criteria}\} \quad (12)$$

and

$$J' = \{j = 1, 2, ..., p \ / \ j \ \textit{associated with cost criteria}\} \quad (13)$$

The larger the attribute outcomes, the greater the preference for the 'benefit' attributes and the lesser the preference for the 'cost' attributes. Thus, r^* is a vector holding the maximum value of each benefit attribute and the minimum value of each cost attribute. Similarly, r^- is a vector holding the minimum value of each benefit attribute and the maximum value of each cost attribute. Consequently, the two new sets of projects, r^* and r^-, represent the most preferable project (ideal solution) and the least preferable project (nadir solution), respectively. Note that the ideal and nadir IT projects are not perfect projects, but rather the best and worst solutions provided by a given decision matrix.

Step 2.2 Calculating the separation measures

The separation between each project can be measured by the n-dimensional Euclidean distance. The separation of each project from the ideal project is given by:

$$S_i^* = \sqrt{\sum_{j=1}^{p}(c_{ij} - c_j^*)^2} \quad (i = 1, 2, ..., n) \tag{14}$$

and, the separation of each project from the nadir project is given by:

$$S_i^- = \sqrt{\sum_{j=1}^{p}(c_{ij} - c_j^*)^2} \quad (i = 1, 2, ..., n) \tag{15}$$

Phase 3 Collective preference ordering modification

Next, the best project is selected by considering various constraints. The separation of each project from the ideal and the nadir IT projects is used as the coefficient of the objective function in the following MODM model with a series of applicable constraints:

$$Max.\ Z_1 = S_1^* r_1 + S_2^* r_2 + ... + S_n^* r_n \quad \text{(Model } P\text{)}$$

$$Min.\ Z_2 = S_1^- r_1 + S_2^- r_2 + ... + S_n^- r_n$$

subject to

$$G(r_1, r_2, ..., r_n) \le 0$$
$$r_i = 0,1$$
$$(i = 1, 2, ..., n)$$

where

$G(r_1, r_2, ..., r_n)$ is a given function of the n projects.

The optimal solution for model (*P*) is the modified collective preference ordering. Next, the proposed framework is illustrated with a numerical example.

4 Case study[1]

Penrose Mills is a complete textile sourcing, manufacturing, warehousing and distribution company located in Philadelphia with a primary focus on industrial and custom fabric applications. The MADM-MODM approach proposed in this study was used to assess eight IT projects at Penrose Mills. The following is a listing of the eight projects along with their initial investments:

Project 1 cable network for ten PC ($18,000)

Project 2 wireless network for ten PC ($34,200)

Project 3 static website ($3,000)

Project 4 DYNAMIC website ($15,000)

Project 5 e-commerce ($12,000)

Project 6 electronic advertisement ($13,300)

Project 7 ADSL establishment with Project 1 or 2 as pre-requirement ($9,400)

Project 8 point-to-point wireless internet connection ($52,700).

There were two constraints to be considered:

1 the total budget could not exceed $55,000

2 the following projects could not be selected simultaneously: Projects 1 and 2, Projects 3 and 4, and Projects 7 and 8.

A committee of four DMs, including the chief executive officer, an executive board representative, the IT manager and the marketing manager, was selected to participate in the project evaluation and selection process. All projects were evaluated on ten attributes identified by the committee:

1 one-time expenses

2 ongoing expenses

3 information accessibility efficiency

4 internal communication efficiency

5 customer acceptance and satisfaction

6 installation time

7 external communication efficiency

8 human skill needs

9 customer response efficiency

10 teamwork productivity.

Phase 1

Step 1.1

Initially, equations (1) and (3) were used to develop the individual and group weights. Table 1 shows the individual and group weights for the ten attributes. The individual weights are given for each of the four DMs. Although there are some differences between the DMs, there was a general agreement among them concerning the attribute weightings. The first three attributes were given higher weights by the majority of the DMs while the last three were given lower weights. The only DM that differed significantly from the others was DM 2 who assigned a relatively low weight for attribute 3 and a relatively high weight for attributes 5 and 8. This table also shows the overall group weights for each of the ten attributes. Note that DM 2 had a significant effect on the group weights so that attribute 3 received a relatively low group weight and attributes 5 and 8 received relatively high weights.

Next, equation (4) was used to calculate the individual DM vector of voting powers. Table 1 shows the individual voting powers for all DMs and attributes. For example, the voting power of DMs 1 and 4 for attribute 1 were twice as much as the voting power of DM 2 for this attribute and four times as much as DM 3. Note that some DMs assigned higher weights to different attributes. For example, DMs 1 and 4 gave the highest weight to attribute 1 and DM 3 gave the most weight to attribute 3.

Table 1 The individual and group weights for the ten attributes

Individual and group weight vectors	*Attribute*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
$W^1 = [w_1^1, w_2^1, ..., w_{10}^1]$	0.160	0.140	0.150	0.100	0.110	0.070	0.090	0.070	0.050	0.030
$W^2 = [w_1^2, w_2^2, ..., w_{10}^2]$	0.200	0.120	0.040	0.100	0.900	0.080	0.070	0.500	0.040	0.020
$W^3 = [w_1^3, w_2^3, ..., w_{10}^3]$	0.180	0.160	0.130	0.100	0.100	0.100	0.080	0.060	0.060	0.040
$W^4 = [w_1^4, w_2^4, ..., w_{10}^4]$	0.180	0.140	0.130	0.100	0.100	0.090	0.090	0.070	0.060	0.040
$W = [w_1, w_2, ..., w_{10}]$	*0.176*	*0.138*	*0.128*	*0.100*	*0.260*	*0.075*	*0.084*	*0.191*	*0.052*	*0.030*

Table 2 The individual voting powers

Individual voting power vectors	*Attribute*				
	1	*2*	*3*	*4*	*5*
$V(q)^1 = [v(q)_1^1, v(q)_2^1, ..., v(q)_{10}^1]$	0.200	0.150	0.050	0.050	0.150
$V(q)^2 = [v(q)_1^2, v(q)_2^2, ..., v(q)_{10}^2]$	0.100	0.100	0.050	0.150	0.100
$V(q)^3 = [v(q)_1^3, v(q)_2^3, ..., v(q)_{10}^3]$	0.050	0.050	0.200	0.050	0.200
$V(q)^4 = [v(q)_1^4, v(q)_2^4, ..., v(q)_{10}^4]$	0.200	0.200	0.050	0.050	0.050
Individual voting power vectors	*Attribute*				
	6	*7*	*8*	*9*	*10*
$V(q)^1 = [v(q)_1^1, v(q)_2^1, ..., v(q)_{10}^1]$	0.050	0.100	0.050	0.050	0.050
$V(q)^2 = [v(q)_1^2, v(q)_2^2, ..., v(q)_{10}^2]$	0.100	0.050	0.100	0.100	0.100
$V(q)^3 = [v(q)_1^3, v(q)_2^3, ..., v(q)_{10}^3]$	0.150	0.050	0.050	0.100	0.050
$V(q)^4 = [v(q)_1^4, v(q)_2^4, ..., v(q)_{10}^4]$	0.150	0.050	0.150	0.050	0.050

Following the voting power calculations, equation (5) was employed to develop four individual decision matrices. Table 3 shows the individual decision matrices for all four DMs. The valuations for the first two attributes, one-time expenses and ongoing expenses, were similar for all DMs. While the four DMs were largely in agreement about these expenses, they gave a significantly higher value for attribute 6, the installation time, for Projects 1 and 4. The remaining attributes were measured by their rank orders. The rankings among the four DMs are fairly consistent.

Table 3 Individual decision matrices

Decision matrix for DM O_1

Project number	Attribute 1	2	3	4	5	6	7	8	9	10
1	18,000	14,400	1	1	3	12	8	8	1	1
2	34,200	14,400	2	2	2	1	7	7	2	2
3	3,000	1,000	6	8	7	7	3	4	4	7
4	15,000	5,000	5	7	1	30	2	3	3	6
5	12,000	5,000	7	3	4	1	1	1	5	3
6	13,300	0	8	6	8	0	4	2	8	8
7	9,400	14,400	3	4	6	2	6	5	7	4
8	52,700	14,400	4	5	5	3	5	6	6	5

Decision matrix for DM O_2

Project number	Attribute 1	2	3	4	5	6	7	8	9	10
1	18,000	14,000	1	1	3	10	8	8	1	1
2	34,000	14,000	2	2	2	1	7	7	2	2
3	3,000	1,000	6	8	7	9	3	4	4	7
4	15,500	5,500	5	7	1	25	2	3	3	6
5	12,000	5,000	7	3	4	2	1	1	5	3
6	13,000	0	8	6	8	0	4	2	8	8
7	9,500	14,000	3	4	6	3	6	5	7	4
8	53,500	14,000	4	5	5	3	5	6	6	5

Decision matrix for DM O_3

Project number	Attribute 1	2	3	4	5	6	7	8	9	10
1	17,500	13,500	2	2	2	11	8	6	1	3
2	33,500	13,500	3	4	3	1	7	8	2	1
3	3,000	1,000	4	8	8	5	3	4	4	5
4	15,500	5,000	8	7	1	27	2	2	3	7
5	12,000	5,000	7	1	4	1	1	3	5	2
6	12,500	0	6	6	6	0	4	1	8	8
7	9,400	13,500	1	3	7	2	6	5	7	6
8	53,500	14,000	5	5	5	2	5	7	6	4

Table 3 Individual decision matrices (continued)

Decision matrix for DM O_4										
Project number	*Attribute*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	18,000	14,000	1	1	3	12	7	8	2	1
2	34,000	14,000	2	3	2	1	6	7	1	2
3	3,000	1,000	6	6	7	5	3	4	4	7
4	15,000	5,000	5	7	1	32	2	3	3	6
5	12,000	5,000	7	4	4	1	1	1	5	3
6	13,0000	0	8	8	8	0	4	2	8	8
7	9,400	14,400	3	5	6	2	8	5	7	4
8	52,000	14,400	4	2	5	3	5	6	6	5

Step 1.2

Equation (6) was used to develop the normalised individual decision matrices. Table 4 shows a matrix for each DM. This table provides a detailed comparative analysis of each value from one attribute to another and shows which attributes had significant impact on the project values. For example, Projects 1 and 2 had relatively high scores for both attributes 4 and 5 while Projects 6, 7 and 8 had a relatively high score for attributes 5, 6 and 7.

Table 4 Normalised individual decision matrices

Normalised decision matrix for DM O_1										
Project number	*Attribute*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.073	0.073	0.219	0.584	0.584	0.073	0.073	0.113	0.210	0.215
2	0.146	0.146	0.146	0.511	0.511	0.146	0.146	0.216	0.210	0.018
3	0.438	0.584	0.511	0.219	0.292	0.292	0.511	0.019	0.015	0.125
4	0.365	0.511	0.073	0.146	0.219	0.219	0.438	0.095	0.073	0.537
5	0.511	0.219	0.292	0.073	0.073	0.365	0.219	0.076	0.073	0.018
6	0.584	0.438	0.584	0.292	0.146	0.584	0.584	0.084	0.000	0.000
7	0.219	0.292	0.438	0.438	0.365	0.511	0.292	0.059	0.210	0.036
8	0.292	0.365	0.365	0.365	0.438	0.438	0.365	0.332	0.210	0.036

Table 4 Normalised individual decision matrices (continued)

Normalised decision matrix for DM O_2

Project number	Attribute									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.073	0.073	0.219	0.584	0.584	0.073	0.073	0.113	0.204	0.179
2	0.146	0.146	0.146	0.511	0.511	0.146	0.146	0.214	0.204	0.018
3	0.438	0.584	0.511	0.219	0.292	0.292	0.511	0.019	0.015	0.161
4	0.365	0.511	0.073	0.146	0.219	0.219	0.438	0.098	0.080	0.448
5	0.511	0.219	0.292	0.073	0.073	0.365	0.219	0.076	0.080	0.036
6	0.584	0.438	0.584	0.292	0.146	0.584	0.584	0.082	0.000	0.000
7	0.219	0.292	0.438	0.438	0.365	0.511	0.292	0.060	0.204	0.036
8	0.292	0.365	0.365	0.365	0.438	0.438	0.365	0.337	0.204	0.036

Normalised decision matrix for DM O_3

Project number	Attribute									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.146	0.146	0.146	0.584	0.438	0.073	0.219	0.110	0.197	0.197
2	0.219	0.292	0.219	0.511	0.584	0.146	0.073	0.211	0.197	0.018
3	0.292	0.584	0.584	0.219	0.292	0.292	0.365	0.019	0.015	0.090
4	0.584	0.511	0.073	0.146	0.146	0.219	0.511	0.098	0.073	0.483
5	0.511	0.073	0.292	0.073	0.219	0.365	0.146	0.076	0.073	0.018
6	0.438	0.438	0.438	0.292	0.073	0.584	0.584	0.079	0.000	0.000
7	0.073	0.219	0.511	0.438	0.365	0.511	0.438	0.059	0.197	0.036
8	0.365	0.365	0.365	0.365	0.511	0.438	0.292	0.337	0.204	0.036

Normalised decision matrix for DM O_4

Project number	Attribute									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.073	0.073	0.219	0.511	0.584	0.146	0.073	0.113	0.204	0.215
2	0.146	0.219	0.146	0.438	0.511	0.073	0.146	0.214	0.204	0.018
3	0.438	0.438	0.511	0.219	0.292	0.292	0.511	0.019	0.015	0.090
4	0.365	0.511	0.073	0.146	0.219	0.219	0.438	0.095	0.073	0.573
5	0.511	0.292	0.292	0.073	0.073	0.365	0.219	0.076	0.073	0.018
6	0.584	0.584	0.584	0.292	0.146	0.584	0.584	0.082	0.000	0.000
7	0.219	0.365	0.438	0.584	0.365	0.511	0.292	0.059	0.210	0.036
8	0.292	0.146	0.365	0.365	0.438	0.438	0.365	0.328	0.210	0.036

Step 1.3

Equation (9) was used to develop the weighted normalised collective matrix. Table 5 shows this matrix for the valuation of each project on each attribute considering the individual voting power of the DMs as well as the overall weights of the attributes. Table 5 also gives a more detailed representation of how each attribute contributed to the overall valuation of the projects. A closer examination of this table reveals that attribute 5, customer acceptance and satisfaction, contributed a relatively high degree of value to Projects 1, 2, 3, 7 and 8. In contrast, attributes 9 and 10, customer response efficiency and teamwork productivity seemed to have almost no effect on the overall value of the projects.

Table 5 The weighted normalised collective matrix

Project number	*Attribute*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.014	0.011	0.005	0.057	0.198	0.007	0.009	0.022	0.011	0.000
2	0.027	0.026	0.005	0.050	0.303	0.009	0.011	0.041	0.011	0.000
3	0.075	0.073	0.015	0.022	0.164	0.022	0.040	0.004	0.001	0.000
4	0.068	0.071	0.002	0.015	0.106	0.017	0.038	0.018	0.004	0.000
5	0.090	0.032	0.008	0.007	0.074	0.028	0.017	0.014	0.004	0.000
6	0.100	0.069	0.014	0.029	0.065	0.044	0.049	0.016	0.000	0.000
7	0.036	0.043	0.013	0.046	0.204	0.039	0.027	0.011	0.011	0.000
8	0.053	0.038	0.010	0.037	0.262	0.033	0.029	0.063	0.011	0.000

Phase 2

Step 2.1

Equations (10) and (11) were used to define two sets of ideal and nadir artificial projects. Table 6 shows the values for the ideal and the nadir projects. An artificial project labelled the ‘ideal project’ was formulated with the minimum and maximum scores associated with each project:

$$r^* = \{0.014, 0.011, 0.015, 0.057, 0.0303, 0.007, 0.049, 0.063, 0.011, 0.000\}$$

Similarly, an artificial project called the ‘nadir project’ was formulated with the minimum and maximum scores associated with each project:

$$r^- = \{0.100, 0.073, 0.002, 0.007, 0.065, 0.004, 0.000, 0.000\}$$

Table 6 The ideal and nadir artificial projects

Project	*Attribute*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
Ideal	0.014	0.011	0.015	0.057	0.303	0.007	0.049	0.063	0.011	0.000
Nadir	0.100	0.073	0.002	0.007	0.065	0.044	0.009	0.004	0.000	0.000

Step 2.2

Equations (14) and (15) were used to calculate the separation measures. Table 7 gives the separations measures for each project from both the ideal and nadir projects. Projects with a relatively low separation from the ideal, such as Projects 1, 2, 7 and 8, and a relatively high separation from the nadir, such as Projects 1, 2 and 7, were preferred. Although Projects 1 and 2 performed well on the separation measures, the selection of the optimal projects were determined by finding the solution to the 0–1 linear programming model presented next.

Table 7 Calculating the separation measures

Project	S_i^*	S_i^-
1	0.60	1.10
2	0.60	0.94
3	0.78	0.71
4	0.97	0.54
5	0.95	0.46
6	0.90	0.72
7	0.59	0.76
8	0.59	0.71

Phase 3

Finally, the separation measure of project i from the ideal and nadir solutions were used as the coefficient of the objective functions in the following MODM model with 0–1 variables:

$$Max.\ Z_1 = 0.60r_1 + 0.60r_2 + 0.78r_3 + 0.97r_4 + 0.95r_5 + 0.90r_6 + 0.59r_7 + 0.59r_8$$

$$Min.\ Z_2 = 1.10r_1 + 0.94r_2 + 0.71r_3 + 0.54r_4 + 0.46r_5 + 0.72r_6 + 0.76r_7 + 0.71r_8$$

subject to

$$r_1 + r_2 = 1$$

$$r_3 + r_2 = 1$$

$$r_7 + r_8 = 1$$

$$31{,}845r_1 + 47{,}895r_2 + 4{,}000r_3 + 20{,}367r_4 + 1{,}700r_5 + 12{,}947r_6 + 23{,}495r_7 + 67{,}120r_8 + \leq 55{,}000$$

$$r_i = 0,1 \quad (i = 1, 2, ..., 8)$$

Table 8 Geometric means for attributes 1 and 2

Project number	*Attribute 1*				*Attribute 1 averages*	*Attribute 2*				*Attribute 2 averages*	*Sum of attributes 1 and 2 averages*
	O_1	O_2	O_3	O_4		O_1	O_2	O_3	O_4		
1	18,000	18,000	17,500	18,000	17,875	14,400	14,000	13,500	14,000	13,975	31,850
2	34,200	34,000	33,500	34,000	33,925	14,400	14,000	13,500	14,000	13,975	47,900
3	3,000	3,000	3,000	3,000	3,000	1,000	1,000	1,000	1,000	1,000	4,000
4	15,000	15,500	15,500	15,000	15,250	5,000	5,500	5,000	5,000	5,125	20,375
5	12,000	12,000	12,000	12,000	12,000	5,000	5,000	5,000	5,000	5,000	17,000
6	13,300	13,000	12,500	13,000	12,950	0	0	0	0	0	12,950
7	9,400	9,500	9,400	9,400	9,425	14,400	14,000	13,500	14,400	14,075	23,500
8	52,700	53,500	53,500	52,000	52,925	14,400	14,000	14,000	14,400	14,200	67,125

The coefficients of the fourth constraint are provided in Table 8. As shown in this table, the geometric means of attributes 1 and 2 were used as coefficients of the budget constraint in the linear programming model. Projects 1, 3, 5 and 7 were identified as the optimal solution with a total cost of $42,400. The result is a $12,600 slack from the budget constraint of $55,000.

5 Conclusions and future research directions

This paper has presented a hybrid model for evaluation and selection of IT projects. The model draws on MADM and MODM to evaluate those attributes that cannot be easily quantified. The model was applied at Penrose Mills to select the best IT project in a problem with multiple and competing attributes and values. In practice, organisations often fail to follow a systematic and well-structured decision making process for assessing IT projects. The case study shows that the proposed model accommodates the multi-dimensional nature of such problems and generates vital information for selecting the most appropriate IT project.

While previous studies have presented multi-attribute frameworks, they failed to consider both subjective and objective judgements in conjunction with project interdependencies in a systematic and consistent model. Combining MADM and MODM supports both qualitative and quantitative decision attributes, as well as the interdependencies among the projects. The case study shows that the hybrid approach can generate valuable insight that can help DMs consider conflicting objectives and evaluate competing alternatives. In addition, the proposed model is flexible and can be easily modified to handle large-scale problems because there are no limits to the number of attributes or alternatives.

Finally, in traditional MADM and MODM, most of the input variables are assumed to be crisp numerical data (Saremi et al., 2009). In most real-world problems, some of the decision data can be precisely measured while other data cannot. Real numbers are used to represent data which can be precisely assessed. Fuzzy sets can represent those data which cannot be precisely measured (Kulak et al., 2005). In reality, sometimes information about the IT projects is incomplete, uncertain or imprecise. In combination with fuzzy set theories, and especially fuzzy logic as well-established mathematical frameworks, further research in defuzzification and transformation of incomplete, uncertain or imprecise estimates into crisp values is certainly needed. Sensitivity analysis could be conducted to see how changes in the constraints and various input parameters impact the defuzzification results and the optimal solution.

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Notes

1 The company name has been changed to protect the anonymity of all concerned.