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Pacific Asia Conference on Information Systems (PACIS)

6-26-2018

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Completed Research Paper

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Abstract

An effective tool for assessing the sustainability performance of information systems (IS) projects in project management is highly desirable. Such a tool, however, is absent from the literature. This paper presents a multi-criteria analysis approach for effectively evaluating the sustainability performance of IS projects in organizations by extending the technique for order preference by similarity to ideal solution (TOPSIS). The subjective assessments of the decision maker in the IS project evaluation and selection process are represented by linguistic variables approximated by fuzzy numbers. The geometric centre based defuzzification method is used for transforming the weighting fuzzy performance matrix into the crisp performance matrix on which TOPSIS is applied for calculating the overall performance of individual IS project across all the selection criteria and their associated sub-criteria. Such a multi-criteria decision making approach adequately provides organizations with a proactive mechanism for effectively evaluating and selecting IS projects from the sustainability perspective. An example is presented for demonstrating the applicability of the proposed approach in evaluating the sustainability performance of IS projects in organizations.

Keywords: Multi-criteria decision analysis, fuzzy theory, project selection, sustainability performance

Introduction

Sustainability is becoming increasingly important to every organization nowadays due to the rapidly growing world population, the increasing industrial production activities which heavily rely on the consumption of non-renewable resources and the rapid development of emerging economies (Silvius & Schipper 2014). Organizations worldwide are under growing pressure to meet government environmental regulations and compliance standards, to mitigate the environmental impact of their operations, and to address the environmental concern of various stakeholders while at the same time increasing their profitability and improving their competitiveness (Huemann & Silvius 2017).

Project-based organizations perform projects for achieving their business objectives (Project Management Institute 2013).To effectively achieve the organizational sustainability objective in a dynamic environment, the evaluation and selection of appropriate projects for development needs with the consideration of sustainability is of critical importance to the organization (Sanchez 2015).

Much research has been done on sustainability and project management, but few studies focus on the intersection of these two topics (Marcelino-Sadaba et al. 2015; Huemann & Silvius 2017). The existing studies that integrate these two themes focus on the evaluation of the environmental impact of projects, in particular, the construction and engineering projects (Huemann & Silvius 2017). No research has been conducted for evaluating the sustainability performance of the information systems (IS) projects in organizations. This creates an enormous gap in research as to how to incorporate the sustainability assessment in the process of evaluating and selecting IS projects.

Evaluating and selecting IS projects is important in modern organizations (Marnewick 2017). This is because industrial production, service provisioning, and business administration are all heavily dependent on the smooth operations of IS which are expensive to develop, complex to use, and difficult to maintain (Deng & Wibowo 2008). The availability of numerous IS projects, the increasing complexities of these projects, and the pressure to make timely decisions in a dynamic environment further complicate the IS project evaluation and selection process (Yeh et al. 2010; Dutra et al. 2014).

Evaluating the performance of IS projects is complex and challenging. It often involves multiple evaluation criteria and subjective and imprecise assessments. Much research has been done on the development of appropriate multi-criteria approaches for evaluating the performance of traditional IS projects. Deng and Wibowo (2008), for example, develop an intelligent decision support system for facilitating the adoption of most appropriate multi-criteria analysis approach in solving the IS project evaluation and selection problem. Yeh et al (2010) propose a fuzzy multi-criteria group decision making approach for solving the IS projects selection problem. Lee and Kim, (2001) present an integrated multi-criteria approach using Delphi, analytic network process concept and zero-one goal programming for solving the IS project selection problem. Wei et al. (2007) approach the IS project selection problem by proposing a comprehensive framework comprising three main phases, including strategic objective analysis phase, system analysis phase, and group decision-making phase. Dutra et al. (2014) propose an economic-probabilistic model for solving the IS project evaluation and selection problem.

The above studies demonstrate that the development of a multi-criteria approach for evaluating the performance of IS projects is of great practical benefits. Existing studies, however, are not totally satisfactory due to the inadequacy of handling the subjectiveness and imprecision in the evaluation process and the computational effort required (Duan et al. 2010). Furthermore, these approaches have not specifically considered the sustainability performance assessment of the IS projects. The development of an effective approach capable of addressing the above shortcomings is thus desirable.

This paper presents a multi-criteria analysis approach for effectively evaluating the sustainability performance of IS projects in organizations by extending the technique for order preference by similarity to ideal solution (TOPSIS). The subjective assessments of the decision maker in the IS project evaluation and selection process are represented by linguistic variables approximated by fuzzy numbers. The geometric centre based defuzzification method is used for transforming the weighting fuzzy performance matrix into the crisp performance matrix on which TOPSIS is applied for calculating the overall sustainability performance of individual IS projects across all the selection criteria and their associated sub-criteria.

In what follows, an overview of the IS project sustainability evaluation problem is presented with the sustainability criteria and their associated sub-criteria identified, leading to the demonstration of a multi-criteria analysis approach for evaluating the sustainability performance of IS projects and an example for showing the applicability of the approach, followed by a conclusion of this paper.

Sustainability Performance Evaluation of IS Projects

Sustainability is concerned with the development that meets the needs of the present without compromising the ability of future generations to meet their own needs (WCED, 1987). The concept of sustainability is widely accepted as the one based on the integration of economic, environmental, and social goals, known as triple-bottom-line (Martens & DeCarvalho 2014; Huemann & Silvius 2017). Projects are the vehicles for implementing sustainability principles in an organization (Marnewick 2017). To effectively achieve the organizational sustainability objectives in a dynamic environment, the balance and incorporation of the three sustainability dimensions into the project evaluation and selection process ensures adherence to the sustainability principles of the organization.

Much research has been done for identifying the factors and criteria for evaluating the sustainability performance of projects in project management from different perspectives (Huemann & Silvius 2017; Marnewick 2017). Most of the research focus on the construction and engineering projects with an unbalanced view considering the triple-bottom-line (Martens and Carvalho 2017). These studies concentrate on evaluating the sustainability performance of projects from the environmental and economic perspectives. The environmental dimension, for example, is recognized as a major concern of various stakeholders for evaluating and selecting the construction projects because a well-designed projects can effectively reduce the negative impact of the organizational operations on environment and adequately remove some potential health hazards resulted from the implementation of chosen projects (Silvius and Schipper 2014). The economic dimension is also considered as a critical evaluation criteria in the project selection process because projects bring several economic benefits to the organization and the society, including the reduction of operations cost, the improvement of the productivity, the provision of employment, and the generation of wealth in a given situation (Marnewick 2017).

The social dimension of the sustainability is under examined in the project management literature. This aspect, however, needs to be properly incorporated into the sustainability assessment (Valdes-Vasquez and Klotz 2013; Martens and Carvalho 2017). Valdes-Vasquez and Klotz (2013), for example, argue that a truly sustainable construction project must include social considerations about the end users, as well as considerations of the impacts of the project in the community with regards to the safety, health, and education of people involved. Integration of all of these considerations would improve the performance of long-term projects and the quality of life of people affected by those projects.

Morden organizations are striving to be outstanding corporate citizens nowadays due to the increasing pressure from the society that the organization is operating in. Usually organizations have to seriously consider their social responsibilities in adopting a project in a given situation. This is because the initiatives taken by the organization to improve the performance of its activities will help increase the organization's image and reputation.

The need to work toward sustainability by introducing the three dimensions of sustainability including environmental, social, and economic into project management is clear, as discussed above. Based on this line of reasoning, three relevant criteria for evaluating the sustainability performance of IS projects can be identified including Economic sustainability (C_1), Environmental sustainability (C_2), and Social sustainability (C_3). Figure 1 shows the hierarchical structure of the IS projects sustainability performance evaluation problem.

The economic sustainability (C_1) focuses on maximising profit, reducing costs, growing revenue and improving quality, which are considered to be some of the traditional business imperatives (Silvius and Schipper 2014; Marnewick 2017). This is measured by the direct financial benefits (C_{11}) and the indirect benefits (C_{12}). The direct financial benefits (C_{11}) is related to the profitability gained through the effective adoption of IS projects. The indirect benefits (C_{12}) refers to the potential business opportunities explored due to the implementation of IS projects.

The environmental sustainability (C_2) is concerned with the physical environment that people inhabit (Silvius and Schipper 2014; Sanchez 2015). This is assessed by procurement (C_{21}), energy (C_{22}), and waste (C_{23}). The procurement (C_{21}) is related to the selection of suppliers and the sourcing of project materails to help deliver the project in a more sustainable way. The energy (C_{22}) focus on IS project-specific policies regarding energy consumption. This includes the energy consumption of individual team members and the equipment used during the project. The waste (C_{23}) concerns with the way that waste is dealt with during the implementation of IS projects in the organization.

The social sustainability (C_3) refers to the communities in which organizations operate, as well as the employees of an organization, which means organizations should take cognisance of the communities in which they operate and of their employees (Marnewick 2017). This is measured by the labour practices in the workplace (C_{31}), the human rights (C_{32}), the public acceptability (C_{33}), and the corporate reputation (C_{34}). The labour practices in the workplace (C_{31}) is related to the health and safety, the training and education, the values and ethics, and the organizational learning in the workplace. The human rights (C_{32}) reflects on the non-discrimination, and the freedom of association culture in the organization. The public acceptability (C_{33}) refers to the general attitude toward the IS projects of the organization. The corporate reputation (C_{34}) concerns with the stakeholders' satisfaction level regarding the IS projects in the organization.

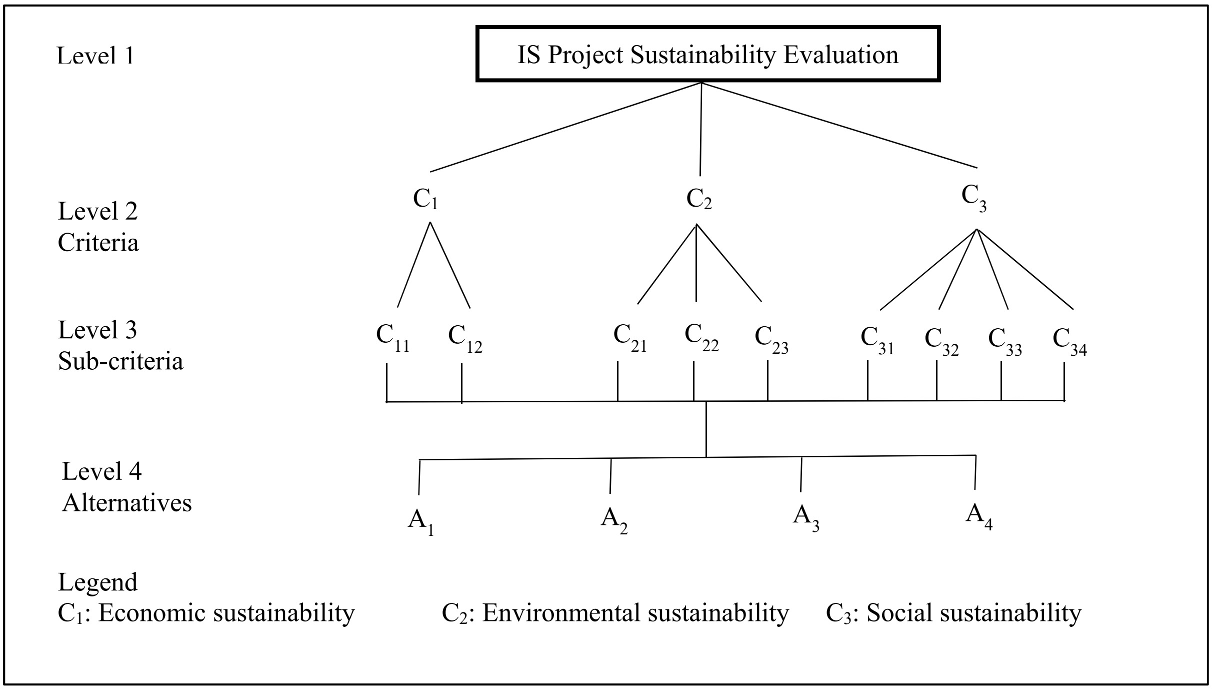

Figure 1. The Hierarchical Structure of IS Projects Sustainability Performance Evaluation

With the identified sustainability criteria and sub-criteria as above, each and every available IS projects has to be comprehensively evaluated for determining their overall performance across all the sustainability evaluation criteria so that the most appropriate IS projects can be selected in a given situation. To effective solve this problem, the next section presents a fuzzy multi-criteria approach for evaluating the sustainability performance of IS projects.

A Multi-Criteria Analysis Approach

Multi-criteria analysis approaches are proven to be effective in tackling problems involving in evaluating and selecting alternatives from a finite number of alternatives with respect to multiple, often conflicting criteria (Duan et al. 2010; Chen and Hwang 2012). The multi-dimensional nature of the IS projects sustainability evaluation process justifies the use of the multi-criteria analysis methodology for solving the IS projects evaluation and selection problems with the consideration of sustainability.

TOPSIS is a popular multi-criteria analysis approach for solving various multi-criteria analysis problems in different areas such as politics, economics, social and management science (Chen and Hwang 2012). The underlying rationale of this approach is that the most preferred alternative should have the shortest distance from the positive ideal solution and at the same time have the longest distance from the negative ideal solution. The popularity of TOPSIS in addressing various practical problems is due to its simplicity and comprehensibility in concept and efficiency in calculation (Deng et al. 2000).

Subjectiveness and imprecision are always present in e-market evaluation and selection due to the presence of (a) incomplete information (b) conflicting evidence, (c) ambiguous information, and (d) subjective information (Yeh et al. 2010; Chen and Hwang 2012). To adequately solve the IS projects sustainability evaluation and selection problem, this section extends the TOPSIS for effectively modelling the subjectiveness and imprecision inherent in the human decision making process with the use of linguistic variables approximated by fuzzy numbers.

A typical IS projects sustainability evaluation problem can be characterized by (a) the available IS projects for evaluation and selection, denoted as alternatives A_i $(i=1, 2, \ldots, n)$ and (b) the multiple sustainability evaluation and selection criteria C_j $(j = 1, 2, \ldots, m)$ and their associated sub-criteria C_{jk} $(k = 1, 2, \ldots, p_j)$ as shown in Figure 1. The IS projects sustainability evaluation process involves in (a) assessing the performance ratings of each IS project with respect to the sustainability criteria and sub-criteria as x_{ij} $(i = 1, 2, \ldots, n, j = 1, 2, \ldots, m)$, (b) determining the relative importance of the sustainability criteria as criteria weights $W = (w_1, w_2, ..., w_j)$ and their associated sub-criteria as sub-criteria weights $W_j = (w_{j1}, w_{j2}, ..., w_{jk})$, and (c) aggregating the performance ratings and sustainability criteria weights for determining the overall performance of individual IS project on which the selection decision can be made.

To adequately model the subjectiveness and imprecision of the IS projects sustainability evaluation and selection process, linguistic variables approximated by triangular fuzzy numbers are used for representing the decision maker's subjective assessments of the sustainability criteria weightings and alternative performance ratings. Triangular fuzzy numbers is usually denoted as (a, b, c) in which b is used to represent the most possible assessment value, and a and c are used to represent the lower and upper bounds used to reflect the fuzziness of the assessment (Deng et al. 2000). Table 1 shows the approximate distribution of the linguistic variables Performance and Importance (Duan et al. 2010) for measuring the alternative performance rating and criteria weightings respectively in the IS projects evaluation and selection process.

Table 1. Linguistic Variables and their Corresponding Triangular Fuzzy Numbers

Performance		Importance	
Linguistic Variable	*Fuzzy Numbers*	*Linguistic Variable*	*Fuzzy Numbers*
Very Poor (VP)	(0.0, 0.0, 0.3)	Very Low (VL)	(0.0, 0.0, 0.3)
Poor (P)	(0.1, 0.3, 0.5)	Low (L)	(0.1, 0.3, 0.5)
Fair (F)	(0.3, 0.5, 0.7)	Medium (M)	(0.3, 0.5, 0.7)
Good (G)	(0.5, 0.7, 0.9)	High (H)	(0.5, 0.7, 0.9)
Very Good (VG)	(0.7, 1.0, 1.0)	Very High (VH)	(0.7, 1.0, 1.0)

Using the linguistic variable Performance defined as in Table 1, the fuzzy decision matrix for the IS projects sustainability evaluation and selection problem can be determined as

$$X = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1m} \\ x_{21} & x_{22} & \cdots & x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ x_{n1} & x_{n2} & \cdots & x_{nm} \end{bmatrix} \quad (1)$$

Where x_{ij} represents the decision maker's assessment of the sustainability performance rating of alternative A_i with respect to the sustainability criteria C_j, which is to be given by the decision maker using linguistic variables or aggregated from a lower-level decision matrix for its associated sub-criteria.

If sub-criteria C_{jk} exist for C_j, a lower-level fuzzy decision matrix can be determined in (2), where y_{jk} is the decision maker's assessment of the performance rating of alternative A_i with respect to sub-criteria C_{jk} of the criteria C_j.

$$Y_{C_j} = \begin{bmatrix} y_{11} & y_{21} & \cdots & y_{n1} \\ y_{12} & y_{22} & \cdots & y_{n2} \\ \cdots & \cdots & \cdots & \cdots \\ y_{1p_j} & y_{2p_j} & \cdots & y_{np_j} \end{bmatrix} \quad (2)$$

The weighting vectors for the sustainability evaluation criteria C_j and sub-criteria C_{jk} can then be given in (3) and (4) by the decision maker using the linguistic variable Importance defined in Table 1.

$$W = (w_1, w_2, ..., w_j) \quad (3)$$

$$W_j = (w_{j1}, w_{j2}, ..., w_{jk}) \quad (4)$$

With the formulation of the lower-level fuzzy decision matrix for the sustainability criteria C_j in (2), and the weight vector in (4) for its associated sub-criteria C_{jk}, the decision vector $(x_{1j}, x_{2j}, \ldots, x_{nj})$ across all the alternatives with respect to criteria C_j in (1) can be determined by

$$(x_{1j}, x_{2j}, ..., x_{nj}) = \frac{W_j Y_{Cj}}{\sum_{k=1}^{p_j} w_{jk}} \quad (5)$$

With the IS projects sustainability evaluation and selection problem described as above, the overall objective for solving the IS projects sustainability evaluation and selection problem is to rank all the alternative IS projects by giving each of them an overall performance rating with respect to all sustainability criteria and their associated sub-criteria. The process of determining the overall performance of each alternative IS project across all the sustainability criteria and their associated sub-criteria starts with calculating the overall weighted performance matrix of all the alternatives with respect to multiple sustainability evaluation and selection criteria by multiplying the criteria weights w_j and the alternative performance rating x_{ij}, shown as follows:

$$Z = \begin{bmatrix} w_1 x_{11} & w_2 x_{12} & \cdots & w_m x_{1m} \\ w_1 x_{21} & w_2 x_{22} & \cdots & w_m x_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ w_1 x_{n1} & w_2 x_{n2} & \cdots & w_m x_{nm} \end{bmatrix} \quad (6)$$

To avoid the complex and unreliable process of comparing fuzzy utilities often required in fuzzy multi-criteria analysis (Yeh et al. 2010), the defuzzification method determined by (7) based on geometric centre of a fuzzy number, is applied to the weighted fuzzy performance matrix in (6) (Chen and Hwang, 2012).

$$r_{ij} = \frac{\int_{S_{ij}} x \mu_{w_j x_{ij}}(x)\, dx}{\int_{S_{ij}} \mu_{w_j x_{ij}}(x)\, dx} \quad (7)$$

Where S_{ij} is the support of fuzzy number $w_j x_{ij}$ in (6). For a triangular fuzzy number (a, b, c), (7) is simplified as (8)

$$r_{ij} = \frac{a + b + c}{3} \quad (8)$$

A weighted performance matrix in a crisp value format can then be obtained as

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix} \quad (9)$$

To rank the alternatives based on (9), the TOPSIS method is applied. To facilitate the use of the TOPSIS method, the concept of the positive-ideal and the negative-ideal solution is used. The positive-ideal solution A^+ and the negative-ideal solution A^-, representing the best possible and the worst possible results among the alternatives respectively across all sustainability criteria, can be determined by

$$A^+ = (r_1^+, r_2^+, ..., r_m^+), \; A^- = (r_1^-, r_2^-, ..., r_m^-) \quad (10)$$

Where

$$r_j^+ = max (r_{1j}, r_{2j}, ..., r_{nj}), \qquad r_j^- = min (r_{1j}, r_{2j}, ..., r_{nj}) \quad (11)$$

From (10) to (11), the distance between alternative A_i and the positive-ideal solution and between alternative A_i and the negative-ideal solution can be calculated respectively by

$$d_i^+ = \sqrt{\sum_{j=1}^{m} (r_j^+ - r_{ij})^2}; \qquad d_i^- = \sqrt{\sum_{j=1}^{m} (r_{ij} - r_j^-)^2} \quad (12)$$

A preferred alternative should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. As a result, an overall performance index for alternative A_i across all criteria can be determined by

$$P_i = \frac{d_i^-}{d_i^+ + d_i^-} \qquad i = 1, 2, ..., n \quad (13)$$

The larger the performance index, the more preferred the alternative.

An Example

To demonstrate the applicability of the proposed multi-criteria approach discussed in the previous section, this section presents an example of evaluating and selecting the most suitable IS projects for an organization from the sustainability perspective.

To start with the IS projects sustainability evaluation and selection process, the performance of each IS project with respect to the sustainability evaluation and selection sub-criteria of each criterion is determined by making the subjective assessment using the linguistic variables as presented in Table 1. Tables 2 shows the assessment results of four alternative IS projects with respect to each sub-criterion.

The relative importance of the IS projects sustainability evaluation criteria and its associated sub-criteria is determined by applying the linguistic variable Importance shown as in Table 1. Table 3 shows the sustainability criteria and its associated sub-criteria weights for the IS projects evaluation and selection.

Table 2. Assessment Results for Each Sub-Criterion

Sub-Criterion	A_1	A_2	A_3	A_4
C_{11}	VG	F	P	F
C_{12}	P	G	VG	P
C_{21}	F	VG	P	P
C_{22}	F	G	G	G
C_{23}	VG	F	F	F
C_{31}	G	P	G	P
C_{32}	G	VP	VG	VG
C_{33}	P	F	G	VG
C_{34}	G	F	VG	G

Table 3. Criteria/Sub-Criteria Weights for IS Projects Sustainability Performance Evaluation

Criterion	Linguistic Weights	Fuzzy Number
C_1	H	(0.5, 0.7, 0.9)
C_{11}	VH	(0.7, 1.0, 1.0)
C_{12}	L	(0.1, 0.3, 0.5)
C_2	M	(0.3, 0.5, 0.7)
C_{21}	H	(0.5, 0.7, 0.9)
C_{22}	M	(0.3, 0.5, 0.7)
C_{23}	VH	(0.7, 1.0, 1.0)
C_3	VH	(0.7, 1.0, 1.0)
C_{31}	M	(0.3, 0.5, 0.7)
C_{32}	VH	(0.7, 1.0, 1.0)
C_{33}	H	(0.5, 0.7, 0.9)
C_{34}	M	(0.3, 0.5, 0.7)

To construct the fuzzy performance matrix for all the alternatives with respect to multiple sustainability evaluation and selection criteria as in equation (1), lower-level fuzzy performance matrix of all the alternatives with respect to sub-criteria determined from Table 2 are aggregated with respect criterion weights in Table 3 using equation (5). Table 4 shows the aggregated fuzzy performance matrix of alternatives with respect to the IS projects sustainability evaluation and selection criteria.

The overall weighted IS projects sustainability performance matrix of all the alternatives with respect to IS projects sustainability evaluation and selection criteria is then calculated using Table 3 and Table 4, based on equation (6). The fuzzy numbers in the overall weighted performance matrix are further converted into comparable crisp numbers, following equation (8). The results are shown in Table 5.

Table 4. Fuzzy Decision Matrix for IS Projects Sustainability Performance Evaluation

	C_1	C_2	C_3
A_1	(0.33, 0.84, 1.56)	(0.28, 0.73, 1.41)	(0.21, 0.60, 1.45)
A_2	(0.17, 0.55, 1.44)	(0.27, 0.70, 1.49)	(0.08, 0.28, 0.98)
A_3	(0.09, 0.46, 1.25)	(0.16, 0.48, 1.19)	(0.33, 0.87, 1.74)
A_4	(0.15, 0.45, 1.19)	(0.16, 0.48, 1.19)	(0.31, 0.81, 1.60)

Table 5. Weighted Performance Matrix in Crisp Numbers

	C_1	C_2	C_3
A_1	0.72	0.48	0.73
A_2	0.59	0.49	0.44
A_3	0.50	0.37	0.95
A_4	0.49	0.37	0.88

Following the approach illustrated in equation (9) to equation (13), an overall performance index for each IS projects across all sustainability criteria can be calculated shown as in Table 6.

Table 6. Performance Index and Ranking for IS projects Sustainability Performance Evaluation

IS projects	Distance		Performance Index	Rank
	$A+$	$A-$	P_i	
A_1	0.22	0.39	0.64	2
A_2	0.53	0.16	0.23	4
A_3	0.25	0.51	0.67	1
A_4	0.27	0.44	0.62	3

It is clear that alternative A_3 is the preferred choice as it has the highest performance index.

Conclusion

Evaluating the performance of alternative IS projects from the sustainability perspective is complex and challenging as it involves in multiple evaluation criteria with the presence of subjective and imprecise assessments in a given situation. This paper has presented a multi-criteria analysis approach for effectively evaluating the sustainability performance of IS projects under uncertainty in an organization. With the use of an example, the proposed multi-criteria analysis approach has demonstrated a number of advantages for adequately dealing with the problem of evaluating the sustainability performance of alternative IS projects in an organization, including the capability to adequately handle the multiple and usually conflicting sustainability criteria, and the ability to deal with the subjectiveness and imprecision inherent in the IS projects performance evaluation problem. The approach is found to be effective and efficient, due to the comprehensibility of its underlying concepts and the straightforward computation process.

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