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# Evaluation model of business intelligence for enterprise systems using fuzzy TOPSIS

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ABSTRACT

Evaluation of business intelligence for enterprise systems before buying and deploying them is of vital importance to create decision support environment for managers in organizations. This study aims to propose a new model to provide a simple approach to assess enterprise systems in business intelligence aspects. This approach also helps the decision-maker to select the enterprise system which has suitable intelligence to support managers' decisional tasks. Using wide literature review, 34 criteria about business intelligence specifications are determined. A model that exploits fuzzy TOPSIS technique has been proposed in this research. Fuzzy weights of the criteria and fuzzy judgments about enterprise systems as alternatives are employed to compute evaluation scores and ranking. This application is realized to illustrate the utilization of the model for the evaluation problems of enterprise systems. On this basis, organizations will be able to select, assess and purchase enterprise systems which make possible better decision support environment in their work systems.



## 1. Introduction

Nowadays, the individual-system approach applied to decision-support such as decision support systems (DSS) has been substitute by a new environmental approach. In the past, DSS were independent systems in an organization and had a frail relationship with other systems (island systems). However, now enterprise systems are the foundation of an organization. And practitioners design and implement business intelligence as umbrella concept create a decision-support environment for management in enterprise systems (Alter, 2004). The increasing trend to use intelligent tools in business systems has increased the need for BI evaluation of enterprise systems.

There are some delimited efforts to evaluate BI, but always they consider BI as tools or separated systems to enterprise systems. Lönnqvist and Pirttimäki (2006) designed BI performance model to measure BI. To this aim, the measurement and the evaluation in BI filed was restricted to prove BI investment worth and BI values. Elbashir, Collier, and Davern (2008) have discussed about measuring the effects of business intelligence systems on business process, and have presented model for effect measures. Also Lin, Tsai, Shiang, Kuo, and Tsai (2009) have developed performance assessment model for business intelligence systems using ANP, but they have considered BI as separated systems again.

Although organizations usually utilize functional and non-functional requirements to evaluate and select enterprise systems, the novel idea create question as follow:

### *1.1. How could organizations evaluate the BI for enterprise systems?*

To fill the gap between use of enterprise system; efficient support decision and BI integrated in work systems; this research has been done to present fuzzy evaluation model. This model can be applied to evaluate and rank candidate enterprise systems like Enterprise Recourse Planning (ERP), Supply Chain Management (SCM), Customer Relationship Management (CRM), and Accounting and Office Automation system. In this regard, organization can choose in a better way for designing, selecting, evaluating and buying enterprise systems with criteria that help them to have better decision support enjoinment in their work systems.

The rest of this paper is prearranged as follows: Section 2 is about past researches attempt to define business intelligence and wide-ranging literature review about BI and decision support criteria to evaluate enterprise systems is summarized in Section 2 too. Section 3 explains general TOPSIS method and stages of new fuzzy TOPSIS method which customized in this paper evaluation model are described in Section 4. The proposed evaluation model based on fuzzy TOPSIS method and evaluation procedures for five enterprise systems with thirty for criteria are illustrated in Section 5. Finally, Section 6 concludes the research work, its findings and proposed future research.

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## 2. Business intelligence

BI refers to a management philosophy and tool that help organizations to manage and refine business information to make effective decisions (Ghoshal & Kim, 1986). The term can be used when referring to the following concepts (Lönnqvist & Pirttimäki, 2006):

1. Related information and knowledge of the organization, which describe the business environment, the organization itself, the conditions of market, customers and competitors and economic issues;
2. A systemic and systematic process by which organizations obtain, analyze and distribute the information for making decisions about business operations.

The purpose of BI is to help control the resources and the information flows of the business, which exist in and around the organization. BI makes a large contribution to the required intelligence and knowledge of the organizations' management by identifying and processing data in order to explain their hidden meanings (Azoff & Charlesworth, 2004).

BI is the process through which organizations take advantage of virtual and digital technology to collect, manage and analyze structural or non-structural data. In other words, the technology and commercial processing procedures in the decision-making are supported through the extraction, integration and analysis of data. Business intelligence is an instrument of analysis providing automated decision-making about business conditions, sales, customer demand and product preference and so on. It uses huge-database (data-warehouse) analysis, as well as mathematical, statistical, artificial intelligence, data mining and on-line analysis processing (OLAP). Eckerson Wayne (2005) understood that BI must be able to provide the following tools: production reporting tools, end-user query and reporting tools, OLAP, dashboard/screen tools, data mining tools and planning and modeling tools. Literature review was done on business intelligence specifications or criteria that a system should have to cover BI definitions. These criteria are listed in Table 1.

## 3. The TOPSIS method

One of the popular methods applied to multiple criteria decision-making is technique for order preference by similarity (TOPSIS). For example, this method has been used by Abo-Sinna and Amer (2005), Cheng, Chan, and Huang (2003), Feng and Wang (2000, 2001), Jee and Kang (2000), Liao (2003), Olson (2004), Opricovic and Tzeng (2004), Tzeng et al. (2005). Also, this method has been used as fuzzy MCDM problem solving.

TOPSIS method which was proposed by Hwang and Yoon (1981) is a technique for order preference by similarity to ideal solution. The ideal solution (also called positive ideal solution) is a solution that maximizes the benefit criteria/attributes and minimizes the cost criteria/attributes, while the negative ideal solution (also called anti-ideal solution) maximizes the cost criteria/attributes and minimizes the benefit criteria/ attributes. The best alternative is the one, which is closest to the ideal solution and farthest from the negative ideal solution (Wang & Elhag, 2006).

**Table 1**
BI evaluation criteria.

| Criteria ID | Criteria name | Related studies |
|---|---|---|
| C1 | Group Sorting tools and methodology (Groupware) | Shim et al. (2002), Reich and Kapeliuk (2005), Damart et al. (2007), Marinoni et al. (2009) |
| C2 | Group decision-making | Eom (1999), Evers (2008), Yu et al. (2009) |
| C3 | Flexible models | Reich and Kapeliuk (2005), Zack (2007), Lin et al. (2009) |
| C4 | Problem clustering | Reich and Kapeliuk (2005), Loebbecke and Huyskens (2007), Lamptey et al. (2008) |
| C5 | Optimization technique | Lee and Park (2005), Nie et al. (2008), Shang et al. (2008), Azadivar et al. (2009), Delorme et al. (2009) |
| C6 | Learning technique | Power and Sharda (2007), Ranjan (2008), Li et al. (2009), Zhan et al. (2009) |
| C7 | Import data from other systems | Özbayrak and Bell (2003), Alter (2004), Shang et al. (2008), Quinn (2009) |
| C8 | Export reports to other systems | Özbayrak and Bell (2003), Shi et al. (2007), Shang et al. (2008) |
| C9 | Simulation models | Power and Sharda (2007), Shang et al. (2008), Quinn (2009), Zhan et al. (2009) |
| C10 | Risk simulation | Evers (2008), Galasso and Thierry (2008) |
| C11 | Financial analyses tools | Santhanam and Guimaraes (1995), Raggad (1997), Gao and Xu (2009) |
| C12 | Visual graphs | Noori and Salimi (2005), Kwon et al. (2007), Power and Sharda (2007), Li et al. (2008), Azadivar et al. (2009) |
| C13 | Summarization | Bolloju et al. (2002), Hemsley-Brown (2005), Power and Sharda (2007), Power (2008) |
| C14 | Evolutionary prototyping model | Fazlollahi and Vahidov (2001), Bolloju et al. (2002), Gao and Xu (2009), Zhang et al. (2009) |
| C15 | Dynamic model prototyping | Koutsoukis et al. (2000), Bolloju et al. (2002), Goul and Corral (2007), González et al. (2008), Pitty et al. (2008) |
| C16 | Backward & forward reasoning | Gottschalk (2006), Evers (2008), Zhang et al. (2009) |
| C17 | Knowledge reasoning | Özbayrak and Bell (2003), Plessis and Toit (2006), Evers (2008) |
| C18 | Alarms and warning | Power (2008), Ross, Dena, and Mahfouf (2009), Zhang et al. (2009) |
| C19 | Dashboard/Recommender | Nemati et al. (2002), Hedgebeth (2007), Bose (2009) |
| C20 | Combination of experiments | Courtney (2001), Nemati et al. (2002), Gottschalk (2006), Gonnet et al. (2007), Ross et al. (2009), Hewett et al. (2009) |
| C21 | Situation awareness modeling | Raggad (1997), Plessis and Toit (2006), Feng et al. (2009) |
| C22 | Environmental awareness | Phillips-Wren et al. (2004), Koo et al. (2008), Güngör Sen et al. (2008) |
| C23 | Fuzzy decision | Metaxiotis et al. (2003), Zack (2007), Makropoulos et al. (2008), Wadhwa et al. (2009), Yu et al. (2009) |
| C24 | OLAP | Tan et al. (2003), Lau et al. (2004), Rivest et al. (2005), Shi et al. (2007), Berzal et al. (2008), Lee et al. (2009) |
| C25 | Data mining techniques | Bolloju et al. (2002), Shi et al. (2007), Berzal et al. (2008), Cheng et al. (2009) |
| C26 | Data warehouses | Tan et al. (2003), Tseng and Chou (2006), March and Hevner (2007), Nguyen et al. (2007) |
| C27 | Web channel | Tan et al. (2003), Oppong et al. (2005), Anderson et al. (2007), Power (2008) |
| C28 | Mobile channel | Power (2008), Wen et al. (2008), Cheng et al. (2009) |
| C29 | E-mail channel | Granebring and Re'vay (2007), Baars and Kemper (2008), Wen et al. (2008) |
| C30 | Intelligent agent | Gao and Xu (2009), Lee et al. (2009), Yu et al. (2009) |
| C31 | Multi agent | Bui and Lee (1999), Xu and Wang (2002), Granebring and Re'vay (2007) |
| C32 | MCDM tools | Hung et al. (2007), Yang (2008), Marinoni et al. (2009), Tansel Iç and Yurdakul (2009) |
| C33 | Stakeholders' satisfaction | Goodhuea et al. (2000), Lönnqvist and Pirttimäki (2006), Evers (2008), González et al. (2008) |
| C34 | Reliability and accuracy of analysis | Gregg et al. (2002), Lönnqvist and Pirttimäki (2006), Phillips-Wren et al. (2007), Zack (2007), González et al. (2008), Power (2008) |

If a MCDM problem has $n$alternatives ($A_1, \ldots, A_n$) and $m$ decision criteria ($C_1,\ldots,C_m$), each alternative is assessed concerning to $m$ criteria. Matrix $X = (x_{ij})_{n\times m}$ show all values that assigned to the alternatives concerning to each criteria. The related weight of each criteria has been shown by $W = (w_1,\ldots,w_m)$.

The steps of TOPSIS method are as a follow:

1. Normalize the decision matrix $X = (x_{ij})_{n\times m}$ using the equation below:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{k=1}^{n} x_{kj}^2}}, \quad i = 1,\ldots,n; \quad j = 1,\ldots,m \tag{1}$$

2. Calculate the weighted normalized decision matrix $V = (v_{ij})_{n\times m}$:

$$v_{ij} = w_j r_{ij}, \quad i = 1,\ldots,n; \quad j = 1,\ldots,m \tag{2}$$

$w_j$ is the relative weight of the $j$th criterion and $\sum_{i=1}^{m} w_j = 1$

3. Determination of the ideal and negative-ideal solutions:

$$A^* = \{v_1^*,\ldots,v_m^*\} = \left\{(\max_j v_{ij} | j \in \Omega_b), (\min_j v_{ij} | j \in \Omega_c)\right\} \tag{3}$$

$$A^- = \{v_1^-,\ldots,v_m^-\} = \{(\min_j v_{ij} | j \in \Omega_b), (\max_j v_{ij} | j \in \Omega_c)\} \tag{4}$$

$\Omega_b$ are the sets of benefit criteria and $\Omega_c$ are the sets of cost criteria

4. Calculate the Euclidean distances of each alternative from the ideal solution and the negative-ideal solution:

$$D_i^* = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^*\right)^2}, \quad i = 1,\ldots,n \tag{5}$$

$$D_i^- = \sqrt{\sum_{j=1}^{m} \left(v_{ij} - v_j^-\right)^2}, \quad i = 1,\ldots,n \tag{6}$$

5. Determination the relative closeness of each alternative to the ideal solution. The relative closeness of the alternative $A_i$ concerning to $A^*$ is characterized as below:

$$RC_i = \frac{D_i^-}{D_i^* + D_i^-}, \quad i = 1,\ldots,n \tag{7}$$

## 4. Fuzzy TOPSIS method

In many real examples, the human preference model is uncertain and decision makers might be hesitant or unable to assign crisp values for judgments (Chan & Kumar, 2007; Shyur & Shih, 2006) and decision-makers often are interested in interval judgments than pointing out their judgments in crisp values (Amiri, 2010). Therefore, one of the problems of traditional TOPSIS is using crisp values in the evaluation process. Another difficulty for using crisp values is that some criteria are difficult to measure by crisp values, so during the evaluation these criteria usually ignored.

The use of fuzzy set theory (Zadeh, 1965) allows the decision-makers to use qualitative information, incomplete information; non-obtainable information and somewhat ignorant facts into decision model (Kulak, Durmusoglu, & Kahraman, 2005).

Thus, fuzzy TOPSIS is developed to solve ranking problems (Büyükzkan, Feyzioglu, & Nebol, 2008; Chen & Tsao, 2007; Onüt & Soner, 2007; Wang & Elhag, 2006).

The current research uses triangular fuzzy number for fuzzy TOPSIS because of ease using a triangular fuzzy number for the decision-makers to calculate. Furthermore, it has verified that modeling with triangular fuzzy numbers is an effective way for formulating decision problems where the information available is subjective and inaccurate (Chang & Yeh, 2002; Chang, Chung, & Wang, 2007; Kahraman, Beskese, & Ruan, 2004).

Some basic important definitions of fuzzy sets are given as below (Amiri, 2010):

1. A triangular fuzzy number $\tilde{a}$ can be defined by a triplet $(a_1,a_2,a_3)$ shown in Fig. 1. The membership function $\mu_{\tilde{a}}(x)$ is defined as:

$$\mu_{\tilde{a}}(x) = \begin{cases} 0 & x < a_1 \\ \frac{x-a_1}{a_2-a_1} & a_1 < x < a_2 \\ \frac{x-a_3}{a_2-a_3} & a_2 < x < a_3 \\ 0 & x < a_3 \end{cases} \tag{8}$$

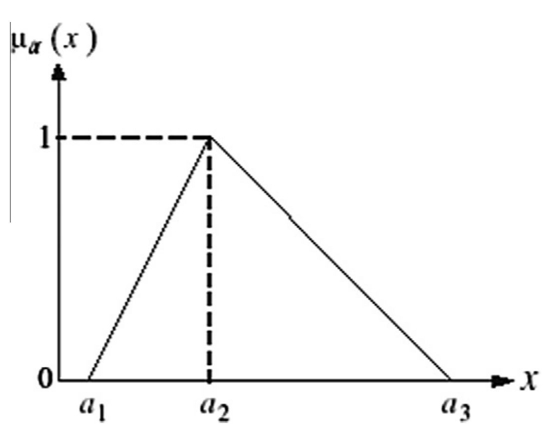


**Fig. 1.** A triangular fuzzy number $\tilde{a}$.

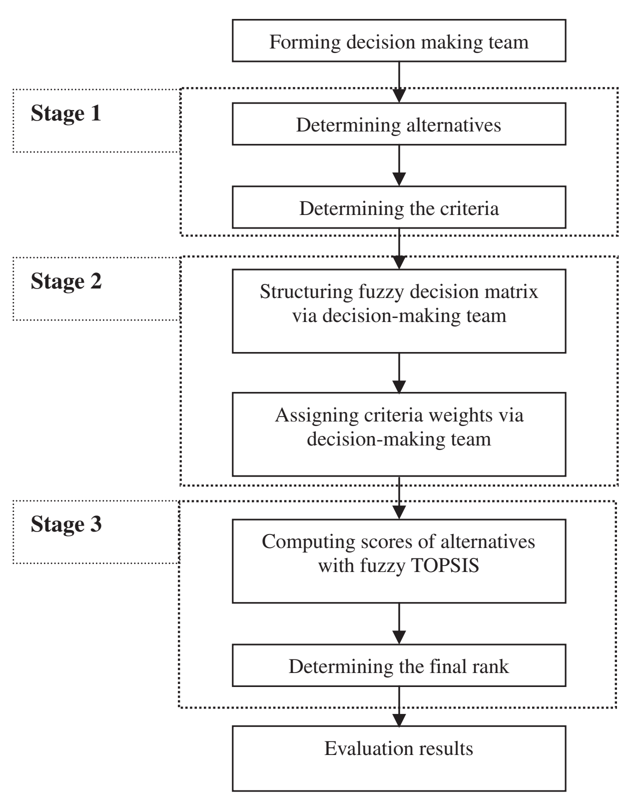


**Fig. 2.** Stages of Fuzzy TOPSIS BI Evaluation Model for enterprise systems.

**Table 2**
Linguistic values and fuzzy numbers.

| Linguistic variables | Fuzzy numbers | Fuzzy numbers |
|---|---|---|
| Very low (VL) | (0,0,0.2) | |
| Low (L) | (0,0.2,0.4) | |
| Medium (M) | (0.2,0.4,0.6) | |
| High (H) | (0.4,0.6,0.8) | |
| Very high (VH) | (0.6,0.8,1) | |
| Excellent (E) | (0.8,1,1) | |

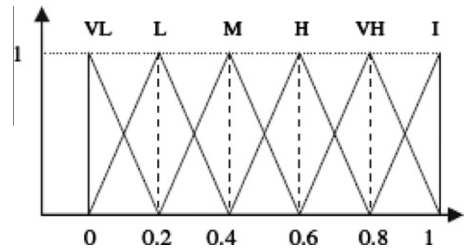


**Table 3**
Fuzzy decision matrix for enterprise systems.

| Enterprise systems | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| ES I | (0,0,0.2) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0,0.2,0.4) | (0.4,0.6,0.8) | (0.2,0.4,0.6) | (0.6,0.8,1) | (0.4,0.6,0.8) | (0.8,1,1) |
| ES II | (0,0.2,0.4) | (0.2,0.4,0.6) | (0,0.2,0.4) | (0,0,0.2) | (0,0,0.2) | (0,0,0.2) | (0.8,1,1) | (0.6,0.8,1) | (0.4,0.6,0.8) |
| ES III | (0.2,0.4,0.6) | (0.4,0.6,0.8) | (0,0.2,0.4) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0,0.2,0.4) | (0.4,0.6,0.8) | (0.4,0.6,0.8) | (0.2,0.4,0.6) |
| ES IV | (0.4,0.6,0.8) | (0.6,0.8,1) | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.4,0.6,0.8) | (0.6,0.8,1) | (0.8,1,1) | (0.8,1,1) | (0,0,0.2) |
| ES V | (0.4,0.6,0.8) | (0.4,0.6,0.8) | (0,0.2,0.4) | (0,0.2,0.4) | (0,0.2,0.4) | (0,0,0.2) | (0.6,0.8,1) | (0.4,0.6,0.8) | (0.4,0.6,0.8) |
| **Weight** | (0.4,0.6,0.8) | (0.6,0.8,1) | (0.4,0.6,0.8) | (0.2,0.4,0.6) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0.6,0.8,1) | (0.6,0.8,1) | (0.4,0.6,0.8) |

| Enterprise systems | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 |
|---|---|---|---|---|---|---|---|---|---|
| ES I | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.8,1,1) | (0.2,0.4,0.6) | (0.6,0.8,1) | (0,0.2,0.4) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0.4,0.6,0.8) |
| ES II | (0,0.2,0.4) | (0,0,0.2) | (0.8,1,1) | (0.4,0.6,0.8) | (0,0,0.2) | (0,0,0.2) | (0,0.2,0.4) | (0,0.2,0.4) | (0.6,0.8,1) |
| ES III | (0.2,0.4,0.6) | (0,0.2,0.4) | (0.4,0.6,0.8) | (0.2,0.4,0.6) | (0,0.2,0.4) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.4,0.6,0.8) |
| ES IV | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.6,0.8,1) | (0.4,0.6,0.8) | (0,0.2,0.4) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0.4,0.6,0.8) | (0.4,0.6,0.8) |
| ES V | (0.4,0.6,0.8) | (0.4,0.6,0.8) | (0.4,0.6,0.8) | (0.8,1,1) | (0,0,0.2) | (0,0,0.2) | (0,0,0.2) | (0,0,0.2) | (0.4,0.6,0.8) |
| **Weight** | (0.2,0.4,0.6) | (0,0.2,0.4) | (0.8,1,1) | (0.6,0.8,1) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0.4,0.6,0.8) | (0.4,0.6,0.8) | (0.6,0.8,1) |

| Enterprise systems | C19 | C20 | C21 | C22 | C23 | C24 | C25 | C26 | C27 |
|---|---|---|---|---|---|---|---|---|---|
| ES I | (0.6,0.8,1) | (0,0,0.2) | (0,0.2,0.4) | (0,0,0.2) | (0,0,0.2) | (0.4,0.6,0.8) | (0.8,1,1) | (0.6,0.8,1) | (0.8,1,1) |
| ES II | (0.8,1,1) | (0,0.2,0.4) | (0,0,0.2) | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.4,0.6,0.8) | (0.6,0.8,1) | (0.6,0.8,1) |
| ES III | (0.4,0.6,0.8) | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.6,0.8,1) | (0.4,0.6,0.8) | (0.8,1,1) |
| ES IV | (0.6,0.8,1) | (0,0,0.2) | (0,0.2,0.4) | (0,0.2,0.4) | (0.4,0.6,0.8) | (0.8,1,1) | (0.6,0.8,1) | (0.8,1,1) | (0.8,1,1) |
| ES V | (0.4,0.6,0.8) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0,0,0.2) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0.6,0.8,1) | (0.4,0.6,0.8) | (0.6,0.8,1) |
| **Weight** | (0.8,1,1) | (0.6,0.8,1) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0.4,0.6,0.8) | (0.6,0.8,1) | (0.6,0.8,1) | (0.8,1,1) | (0.4,0.6,0.8) |

| Enterprise systems | C28 | C29 | C30 | C31 | C32 | C33 | C34 |
|---|---|---|---|---|---|---|---|
| ES I | (0.2,0.4,0.6) | (0,0,0.2) | (0,0,0.2) | (0,0,0.2) | (0.4,0.6,0.8) | (0.2,0.4,0.6) | (0.4,0.6,0.8) |
| ES II | (0.4,0.6,0.8) | (0,0.2,0.4) | (0.4,0.6,0.8) | (0,0.2,0.4) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0,0.2,0.4) |
| ES III | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0,0.2,0.4) | (0.2,0.4,0.6) | (0,0.2,0.4) | (0,0.2,0.4) | (0.2,0.4,0.6) |
| ES IV | (0.2,0.4,0.6) | (0.4,0.6,0.8) | (0,0.2,0.4) | (0,0,0.2) | (0.2,0.4,0.6) | (0.4,0.6,0.8) | (0.2,0.4,0.6) |
| ES V | (0.8,1,1) | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.6,0.8,1) | (0.2,0.4,0.6) | (0.4,0.6,0.8) |
| **Weight** | (0.2,0.4,0.6) | (0.2,0.4,0.6) | (0.6,0.8,1) | (0.6,0.8,1) | (0.6,0.8,1) | (0.8,1,1) | (0.8,1,1) |

2. If $\tilde{a}$ and $\tilde{b}$ were two triangular fuzzy numbers which has been shown by the triplet $(a_1,a_2,a_3)$ and $(b_1,b_2,b_3)$, respectively, then the operational laws of these two triangular fuzzy numbers are as follows:

$$\tilde{a}(+)\tilde{b} = (a_1,a_2,a_3)(+)(b_1,b_2,b_3) = (a_1+b_1,a_2+b_2,a_3+b_3) \quad (9)$$

$$\tilde{a}(-)\tilde{b} = (a_1,a_2,a_3)(-)(b_1,b_2,b_3) = (a_1-b_1,a_2-b_2,a_3-b_3) \quad (10)$$

$$\tilde{a}(\times)\tilde{b} = (a_1,a_2,a_3)(\times)(b_1,b_2,b_3) = (a_1\times b_1,a_2\times b_2,a_3\times b_3) \quad (11)$$

$$\tilde{a}(/)\tilde{b} = (a_1,a_2,a_3)(/)(b_1,b_2,b_3) = (a_1/b_3,a_2/b_2,a_3/b_1) \quad (12)$$

$$\tilde{a} = (ka_1,ka_2,ka_3) \quad (13)$$

3. A linguistic variable which present by words like very low, low, medium, high, very high use to describe complex condition (Zadeh, 1975). These linguistic values can also be represented by fuzzy numbers (Amiri, 2010).

4. If $\tilde{a}$ and $\tilde{b}$ were two triangular fuzzy numbers which has been shown by the triplet $(a_1,a_2,a_3)$ and $(b_1,b_2,b_3)$, respectively, then vertex method is used to determine the distance between $a$ and $b$:

$$d(\tilde{a},\tilde{b}) = \sqrt{\frac{1}{3}\left[(a_1-b_1)^2+(a_2-b_2)^2+(a_3-b_3)^2\right]} \quad (14)$$

5. The weighted normalized fuzzy-decision matrix is made from below formula:

$$\tilde{v} = [\tilde{v}_{ij}]_{n\times j}, \quad i=1,2,\ldots,n, \quad j=1,2,\ldots,m$$
$$\tilde{v}_{ij} = \tilde{x}_{ij} \times W_i \quad (15)$$

A set of presentation rating of $A_j = (j = 1,2,\ldots,m)$ concerning to criteria $C_i = (i = 1,2,\ldots,n)$ named $\tilde{x} = (\tilde{x}_{ij}, i = 1, 2,\ldots, n, j = 1, 2,\ldots, m)$.

**Table 4**
Weighted normalized fuzzy-decision matrix.

| Enterprise systems | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| ES I | (0,0,0.16) | (0,0.16,0.4) | (0.08,0.24,0.48) | (0,0.08,0.24) | (0,0.12,0.32) | (0.04,0.16,0.36) | (0.36,0.64,1) | (0.24,0.48,0.8) | (0.32,0.6,0.8) |
| ES II | (0,0.12,0.32) | (0.12,0.32,0.6) | (0,0.12,0.32) | (0,0,0.12) | (0,0,0.08) | (0,0,0.12) | (0.48,0.8,1) | (0.36,0.64,1) | (0.16,0.36,0.64) |
| ES III | (0.08,0.24,0.48) | (0.24,0.48,0.8) | (0,0.12,0.32) | (0,0.08,0.24) | (0,0.08,0.24) | (0,0.08,0.24) | (0.24,0.48,0.8) | (0.24,0.48,0.8) | (0.08,0.24,0.48) |
| ES IV | (0.16,0.36,0.64) | (0.36,0.64,1) | (0.08,0.24,0.48) | (0.04,0.16,0.36) | (0,0.12,0.32) | (0.12,0.32,0.6) | (0.48,0.8,1) | (0.48,0.8,1) | (0,0,0.16) |
| ES V | (0.16,0.36,0.64) | (0.24,0.48,0.8) | (0,0.12,0.32) | (0,0.08,0.24) | (0,0.04,0.16) | (0,0,0.12) | (0.36,0.64,1) | (0.24,0.48,0.8) | (0.16,0.36,0.64) |

| Enterprise systems | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 |
|---|---|---|---|---|---|---|---|---|---|
| ES I | (0.04,0.16,0.36) | (0,0.08,0.24) | (0.64,1,1) | (0.12,0.32,0.6) | (0,0.16,0.4) | (0,0.08,0.24) | (0,0.12,0.32) | (0.08,0.24,0.48) | (0.24,0.48,0.8) |
| ES II | (0,0.08,0.24) | (0,0,0.08) | (0.64,1,1) | (0.24,0.48,0.8) | (0,0,0.08) | (0,0,0.12) | (0,0.12,0.32) | (0,0.12,0.32) | (0.36,0.64,1) |
| ES III | (0.04,0.16,0.36) | (0,0.04,0.16) | (0.32,0.6,0.8) | (0.12,0.32,0.6) | (0,0.04,0.16) | (0,0.08,0.24) | (0.08,0.24,0.48) | (0.08,0.24,0.48) | (0.24,0.48,0.8) |
| ES IV | (0.04,0.16,0.36) | (0,0.08,0.24) | (0.48,0.8,1) | (0.24,0.48,0.8) | (0,0.04,0.16) | (0,0.08,0.24) | (0.08,0.24,0.48) | (0.16,0.36,0.64) | (0.24,0.48,0.8) |
| ES V | (0.08,0.24,0.48) | (0,0.12,0.32) | (0.32,0.6,0.8) | (0.48,0.8,1) | (0,0,0.08) | (0,0,0.12) | (0,0,0.16) | (0,0,0.16) | (0.24,0.48,0.8) |

| Enterprise systems | C19 | C20 | C21 | C22 | C23 | C24 | C25 | C26 | C27 |
|---|---|---|---|---|---|---|---|---|---|
| ES I | (0.48,0.8,1) | (0,0,0.2) | (0,0.04,0.16) | (0,0,0.12) | (0,0,0.16) | (0.24,0.48,0.8) | (0.48,0.8,1) | (0.48,0.8,1) | (0.32,0.6,0.8) |
| ES II | (0.64,1,1) | (0,0.16,0.4) | (0,0,0.08) | (0.04,0.16,0.36) | (0.08,0.24,0.48) | (0.12,0.32,0.6) | (0.24,0.48,0.8) | (0.48,0.8,1) | (0.24,0.48,0.8) |
| ES III | (0.32,0.6,0.8) | (0.12,0.32,0.6) | (0,0.08,0.24) | (0.04,0.16,0.36) | (0.08,0.24,0.48) | (0.12,0.32,0.6) | (0.36,0.64,1) | (0.32,0.6,0.8) | (0.32,0.6,0.8) |
| ES IV | (0.48,0.8,1) | (0,0,0.2) | (0,0.04,0.16) | (0,0.08,0.24) | (0.16,0.36,0.64) | (0.48,0.8,1) | (0.36,0.64,1) | (0.64,1,1) | (0.32,0.6,0.8) |
| ES V | (0.32,0.6,0.8) | (0,0.16,0.4) | (0,0.08,0.24) | (0,0,0.12) | (0,0.12,0.32) | (0.12,0.32,0.6) | (0.36,0.64,1) | (0.32,0.6,0.8) | (0.24,0.48,0.8) |

| Enterprise systems | C28 | C29 | C30 | C31 | C32 | C33 | C34 |
|---|---|---|---|---|---|---|---|
| ES I | (0.04,0.16,0.36) | (0,0,0.12) | (0,0,0.2) | (0,0,0.2) | (0.24,0.48,0.8) | (0.16,0.4,0.6) | (0.32,0.6,0.8) |
| ES II | (0.08,0.24,0.48) | (0,0.08,0.24) | (0.24,0.48,0.8) | (0,0.16,0.4) | (0,0.16,0.4) | (0.16,0.4,0.6) | (0,0.2,0.4) |
| ES III | (0.04,0.16,0.36) | (0.04,0.16,0.36) | (0,0.16,0.4) | (0.12,0.32,0.6) | (0,0.16,0.4) | (0,0.2,0.4) | (0.16,0.4,0.6) |
| ES IV | (0.04,0.16,0.36) | (0.08,0.24,0.48) | (0,0.16,0.4) | (0,0,0.2) | (0.12,0.32,0.6) | (0.32,0.6,0.8) | (0.16,0.4,0.6) |
| ES V | (0.16,0.4,0.6) | (0.04,0.16,0.36) | (0.12,0.32,0.6) | (0.12,0.32,0.6) | (0.36,0.64,1) | (0.16,0.4,0.6) | (0.32,0.6,0.8) |

A set of importance weights of each criterion $W_i = (i = 1,2,\ldots,n)$,

The steps of fuzzy TOPSIS method which introduced by Onüt and Soner (2007), and is applied in this paper, can be summarized as below.

**Step 1:** Choose the linguistic values ($x_{ij}$, $i = 1,2,\ldots,n$, $j = 1,2,\ldots,m$) for alternatives concerning to criteria. The fuzzy linguistic rating ($x_{ij}$) keeps the ranges of normalized triangular fuzzy numbers belong to [0,1]; hence, there is no need for normalization.

**Step 2:** Compute the weighted normalized fuzzy-decision matrix by Eq. (15)

**Step 3:** Determine positive-ideal (FPIS,$A^*$) and negative-ideal (FNIS,$A^-$) solutions from the equations below:

$$A^* = \{v_1^*, \ldots, v_i^*\} = \{(\max_j v_{ij} | i \in \Omega_b), (\min_j v_{ij} | i \in \Omega_c)\} \quad (16)$$

$$A^- = \{v_1^-, \ldots, v_i^-\} = \{(\min_j v_{ij} | i \in \Omega_b), (\max_j v_{ij} | i \in \Omega_c)\} \quad (17)$$

$\Omega_b$ are the sets of benefit criteria and $\Omega_c$ are the sets of cost criteria

**Step 4:** Calculate the distance of each alternative from $A^*$ and $A^-$by the following equations:

$$D_i^* = \sum_{j=1}^{m} d(\widetilde{V}_{ij}, \widetilde{V}_i) \quad i = 1,2,\ldots,n \quad (18)$$

$$D_i^- = \sum_{j=1}^{m} d(\widetilde{V}_{ij}, \widetilde{V}_i) \quad i = 1,2,\ldots,n \quad (19)$$

**Step 5:** Compute similarities to ideal solution:

$$FC_i = \frac{D_i^-}{D_i^- + D_i^*} \quad (20)$$

## 5. The proposed model

In this research, fuzzy TOPSIS has been used to evaluate enterprise systems with respect to criteria presented in Table 1. There are three stages to evaluate and select the enterprise system based on BI evaluation criteria: (1) determine enterprise systems for evaluation as alternatives, and recognize the criteria to be used in assessment process, (2) structuring fuzzy decision matrix and assigning criteria weights (3) computing scores of alternatives with fuzzy TOPSIS and ranking, finally evaluation report can be utilized. Schematic diagram of these stages is illustrated in Fig. 2. In following sections, this model is applied to solve numerical example.

### 5.1. Identification of alternatives and criteria

In the first stage, five enterprise systems were considered for evaluation that in this paper easy tracking named ES I, ES II, ES III, ES IV and ES V. After that all explored evaluation criteria from literature review were recognized, 34 criteria were determined that can be seen in Table 1 and named C1, C2, …, C34. Linguistic values have been used for evaluation of alternatives and weights of criteria. The membership functions of these linguistic values and the triangular fuzzy numbers related with these variables are shown in Table 2.

**Table 5**
Fuzzy positive and negative ideal solution (FPIS & FNIS).

| FPIS & FNIS | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|
| $A^*$ | (0.16, 0.36, 0.64) | (0.36, 0.64, 1) | (0.08, 0.24, 0.48) | (0.04, 0.16, 0.36) | (0, 0.12, 0.32) | (0.12, 0.32, 0.6) | (0.48, 0.8, 1) | (0.48, 0.8, 1) | (0.32, 0.6, 0.8) |
| $A^-$ | (0, 0, 0.16) | (0, 0.16, 0.4) | (0, 0.12, 0.32) | (0, 0, 0.12) | (0, 0, 0.08) | (0, 0, 0.12) | (0.24, 0.48, 0.8) | (0.24, 0.48, 0.8) | (0, 0, 0.16) |
| | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 |
| $A^*$ | (0.08, 0.24, 0.48) | (0, 0.12, 0.32) | (0.64, 1, 1) | (0.48, 0.8, 1) | (0, 0.16, 0.4) | (0, 0.08, 0.24) | (0.08, 0.24, 0.48) | (0.16, 0.36, 0.64) | (0.36, 0.64, 1) |
| $A^-$ | (0, 0.08, 0.24) | (0, 0, 0.08) | (0.32, 0.6, 0.8) | (0.12, 0.32, 0.6) | (0, 0, 0.08) | (0, 0, 0.12) | (0, 0, 0.16) | (0, 0, 0.16) | (0.24, 0.48, 0.8) |
| | C19 | C20 | C21 | C22 | C23 | C24 | C25 | C26 | C27 |
| $A^*$ | (0.64, 1, 1) | (0.12, 0.32, 0.6) | (0, 0.08, 0.24) | (0.04, 0.16, 0.36) | (0.16, 0.36, 0.64) | (0.48, 0.8, 1) | (0.48, 0.8, 1) | (0.64, 1, 1) | (0.32, 0.6, 0.8) |
| $A^-$ | (0.32, 0.6, 0.8) | (0, 0, 0.2) | (0, 0, 0.08) | (0, 0, 0.12) | (0, 0, 0.16) | (0.12, 0.32, 0.6) | (0.24, 0.48, 0.8) | (0.32, 0.6, 0.8) | (0.24, 0.48, 0.8) |
| | C28 | C29 | C30 | C31 | C32 | C33 | C34 | | |
| $A^*$ | (0.16, 0.4, 0.6) | (0.08, 0.24, 0.48) | (0.24, 0.48, 0.8) | (0.12, 0.32, 0.6) | (0.36, 0.64, 1) | (0.32, 0.6, 0.8) | (0.32, 0.6, 0.8) | | |
| $A^-$ | (0.04, 0.16, 0.36) | (0, 0, 0.12) | (0, 0, 0.2) | (0, 0, 0.2) | (0, 0.16, 0.4) | (0, 0.2, 0.4) | (0, 0.2, 0.4) | | |

**Table 6**
Final computation results.

| Enterprise systems | $D_i^*$ | $D_i^-$ | $FC_i$ |
|---|---|---|---|
| ES I | 5.465016 | 4.202188 | 0.434685 |
| ES II | 5.727552 | 3.960358 | 0.408794 |
| ES III | 5.967252 | 3.676034 | 0.381201 |
| ES IV | 3.459038 | 6.211444 | 0.64231 |
| ES V | 5.013834 | 4.65206 | 0.481286 |

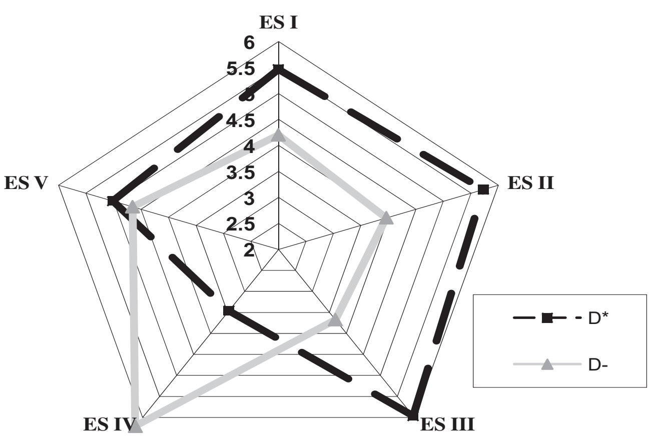


**Fig. 3.** Evaluation of $D_i^*$ & $D_i^-$ for enterprise systems.

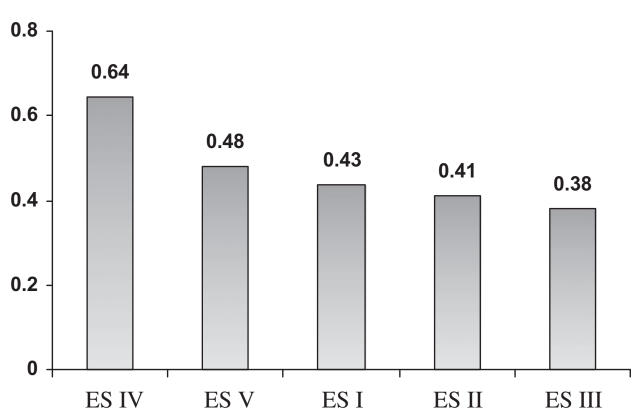


**Fig. 4.** Ranking the evaluated enterprise systems.

### 5.2. Structuring fuzzy decision matrix and assigning weights of criteria

Based on Linguistic variables (Table 2), alternatives with regards to criteria were assessed by decision making team; also they assigned appropriate weights to each criterion. Fuzzy decision averages matrix for enterprise systems was created based on judgment of experts and can be seen in Table 3.

### 5.3. Evaluate alternatives and determine the final rank

After the fuzzy decision matrix was established, the next step is to compute the fuzzy weighted decision matrix that is depicted in Table 4. This matrix is calculated with Eq. (15). Following, by Eqs. (16) and (17), the fuzzy positive-ideal solution (FPIS, $A^*$) and negative-ideal solution (FNIS, $A^-$) were defined. Table 5 shows the results of this step. Then, the Euclidean distance of each alternative from $A^*$ and $A^-$ can be computed by Eqs. (18) and (19). Subsequently, the similarities to an ideal solution are solved by Eq. (20). Finally, the values of each alternative for final ranking have been illustrated in Table 6. Detailed calculations for FC1 similarities to an ideal solution are as below:

$$D_1^* = \sqrt{\frac{1}{3}\left[(0.16-0)^2+(0.36-0)^2+(0.64-0.16)^2\right]} + \sqrt{\frac{1}{3}\left[(0.36-0)^2+(0.64-0.16)^2+(1-0.4)^2\right]} + \dots + \sqrt{\frac{1}{3}\left[(0.32-0.32)^2+(0.6-0.6)^2+(0.8-0.8)^2\right]} = 5.465016$$

$$D_1^- = \sqrt{\frac{1}{3}\left[(0-0)^2+(0-0)^2+(0.16-0.16)^2\right]} + \sqrt{\frac{1}{3}\left[(0-0)^2+(0.16-0.16)^2+(0.4-0.4)^2\right]} + \dots + \sqrt{\frac{1}{3}\left[(0.32-0)^2+(0.6-0.2)^2+(0.8-0.4)^2\right]} = 5.013834$$

$$FC_1 = \frac{D_1^-}{D_1^- + D_1^*} = \frac{4.202188}{4.202188+5.465016} = 0.434685$$

Comparison of $D_1^*, D_2^*, \dots, D_5^*$ and $D_1^-, D_2^-, \dots, D_5^-$ that reflect BI capabilities of enterprise systems, strength and weakness, respectively has been shown in Fig. 3. For example, it can be seen that ES IV has large $D_i^-$ which shows large distance from negative ideal. It also proves this enterprise system have appropriate business intelligence capabilities which enhance decision support in organization. Ranking and fuzzy final score of evaluated enterprise systems have been shown in Fig. 4 (ES IV > ES V > ES I > ES II > ES III).

## 6. Conclusion

The increasing trend to use intelligent tools in work systems has increased the need for business Intelligence evaluation of enterprise systems. In past BI evaluation as a tool or independent system was separated to evaluation of enterprise systems includes Enterprise Recourse Planning (ERP), Supply Chain Management (SCM), Customer Relationship Management (SCM), Accounting and Office Automation system. In this research, with considering BI as enterprise systems non-functional requirements, an evaluation model for enterprise systems using fuzzy TOPSIS was develop. BI definition and BI evaluation criteria were gathered by large literature review in BI researches. After describing general TOPSIS method, a new customized fuzzy TOPSIS method with detailed stages was described. With following proposed evaluation model, five enterprise systems with those 34 criteria was assessed by decision-making team and fuzzy positive and negative ideal solution were determined. After that by computing final fuzzy score for each enterprise system and comparing them, the ranking of evaluated enterprise systems was presented.

Applying other MCDM methods in fuzzy environment to evaluate enterprise systems by considering BI criteria, comparing these methods and developing expert system to select best enterprise system with high intelligence level are recommended for future research. The authors believe that after this research, organization can decide in a better way for designing, selecting, evaluating and buying enterprise systems with criteria and model that help them to have better decision support environment in their work systems.

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