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Framework for prioritizing and allocating six sigma projects using fuzzy TOPSIS and fuzzy expert system

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Abstract. The project selection process can be recognized as the most important action in the success of six sigma projects. In this way, ranking and assigning projects to implementation teams is considered the most important step in this process. Copious research has been undertaken into Six Sigma Project Selection (SSPS), none of which, however, has been focused on selecting and allocating projects as a coherent process, simultaneously. In this regard, this article presents a framework for decision making, selecting and assigning the six sigma projects to implementation teams. First, the most important criteria in the SSPS process are selected. Subsequently, after identifying six sigma potential projects in the organization, the fuzzy TOPSIS methodology is utilized to prioritize them. Afterwards, the Impact and Effort indexes for each project are calculated. Then, the Takagi-Sugeno-Kang (TSK) Fuzzy Expert System is used to allocate the projects to six sigma specialists. Finally, a case study in the automobile industry is presented and the framework is discussed to illustrate its developed application.

1. Introduction

Technology dominates current industry, paving the way for construction of dynamic environments. Meanwhile, organizations require constant change in order to survive fierce competition, at the mercy of quality improvement and cost reduction. In this regard, six sigma is considered one of the most popular tools for waste elimination, cost reduction and quality improvement throughout organizations [1]. In order to implement six sigma projects, a five-step process, named DMAIC (Define, Measure, Analyze, Improve and Control), is considered the key to achieving project goals [2], and to continuously define and solve any problems [3,4]. Results and improvements in time are considered manifest features of this approach [5,6]. Six sigma clearly relates technical activities to strategic activities. Consequently, a developed six sigma project can be compatible with international results-oriented quality awards, such as the European Quality Award, the Malcolm Baldrige National Quality Award (MBNQA), Canada Awards for Excellence and Quality Awards-Australian [7]. Przekop showed, by comparison between MBNQA and six sigma programs, that both are focused on method, customers, collaboration, data-oriented management and strategic plans [8]. Therefore, quality award criteria can be known as project selection criteria in the success of six sigma projects. Although this topic has been generally attended to by researchers, few are related to Six Sigma Project Selection (SSPS).

Recently, a few researchers have focused on the

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issue of SSPS. These include Snee (2002) and Dickman (2003) who have worked on six sigma criteria identification and developed a multi-criteria decision making model for ranking six sigma projects [9,10]. Su and Chia (2008) systematically studied the identification and creation of SSPS criteria and considered the ranking of six sigma projects using a fuzzy Analytic Hierarchy Process (AHP) [5]. Kumar et al. (2007) provided a Data Envelopment Analysis (DEA) model using identification of the input and output of projects for six sigma project performance evaluation [11]. Kahraman and Büyükzkan (2008) presented a weighted additive fuzzy goal programming methodology by the AHP method for the best suitable six sigma project portfolio [12]. Yang and Hsieh (2008) developed a Fuzzy AHP decision making model for evaluating and selecting six sigma projects [13]. Saghaei and Didehkhani (2010) presented a fuzzy goal programming model and Adaptive Neuro-Fuzzy Inference Systems (ANFIS) for evaluating and selecting six sigma projcts [1].

It is clear that the prioritizing of six sigma projects is discussed in research, but there has been no model developed for allocating projects to executive teams and six sigma experts. In addition, there is no model which prioritizes and selects six sigma projects, and also allocates them to related specialists, simultaneously. Therefore, this paper is innovative in endeavouring to develop a comprehensive framework, presenting a step by step process to identify potential six sigma projects throughout an organization, to prioritize potential projects using fuzzy TOPSIS, and allocate them to specialists, according to their proficiencies, through a fuzzy expert system method, at the same time.

The rest of the paper has the following structure. The next section is related to research literature in which, six sigma methodology, six sigma potential project identification, fuzzy TOPSIS, and the method of project allocation have been studied. The model includes introduction of the research methodology, and the presented model in this study is explained in Section 3. Section 4 states implementation of the presented framework as a case study, and, finally, Section 5 is devoted to conclusions and suggestion for future research.

2. Literature review

2.1. Six sigma and SSPS criteria

Six sigma was first developed by Motorola in 1987 and was commonly utilized by General Electric in early 1995 [14]. Its purpose was to produce long-term defect levels, below 3.4 Defects Per Million Opportunities (DPMO) [15,16]. Six sigma can be called an invention for producing high level results, improving operational processes, enhancing employee skills and encouraging changes [17].

From the perspective of experts, six sigma is defined as an efficient and data-oriented approach for analyzing business problems and their root causes in order to solve them. Consequently, this methodology is known to be one of the most effective methods among the plethora of ways to improve businesses [18]. Six sigma has been used throughout the world and many companies have confirmed its pivotal role in their success [19]. This approach focuses on reducing variations in processes, such as manufacturing processes, administrative processes, etc. [20]. Six sigma is a technical tool for creating value, with the purpose of attaining operational advantages that pave the ground for achieving business success [7]. If six sigma projects are wrongly selected from the beginning, they will be inefficient and lead to a loss in time and costs [5]. Therefore, one of the most essential and critical stages in the process of six sigma is project selection [9]. According to studies carried out in this area, a set of potential criteria that can be utilized in selecting important six sigma projects are known and presented as follows:

- Direct relations with strategic objectives [10,21];
- Customer satisfaction [21];
- Financial efficiency-increasing profits [21,22];
- The organization's key processes [21];
- Investment returns [23,24];
- Ability to access information [21];
- Special need to improve [10] measurability [25];
- Needed time [26,27];
- Resource availability (including manpower) [21];
- Employee satisfaction from projects [21];
- Project scope [10].

2.2. Identifying the six sigma potential projects

A collection of information from various accessible sources can be used in potential project identification [9]. In this regard, the most important and relevant sources are:

(i) Customer satisfaction evaluation results: Customers are the first beneficiaries of reduced damage [5];

(ii) Voice Of Customers (VOC): Telephone services, correspondence services, internet services and focused groups are considered major sources for collecting VOC [10];

(iii) Suppliers: an overall look at the processes causes a belief that suppliers are also considered a part of the process. Ignoring the supplier and consumer generates some problems for the project selection process [9];

(iv) Employees: The organization's employees are potential project identification resources [15];

(v) Previous projects: On hand projects or done projects can present some proposals for identifying potential projects (future projects should not conflict with current projects or intervene in their affairs);

(vi) Competitor analysis: This action can lead to improvement in competitive advantages and increase the competitions power, especially in competitive environments [3];

(vii) Waste identification: Studying seven types of waste, i.e. waiting, inventory, defects, overprocessing, overproduction, unnecessary transportation and motion, can be an encouragement and operate as an informative source of potential project identification [28];

(viii) Cost Of Quality (COQ) reports [29], also, the role of income opportunities related to capacity and sale, and strategic goal reconsideration [4,30] should not be simply overlooked.

Finally, six sigma potential projects can be identified in each company by collecting information from the aforementioned sources and brainstorming meetings [6].

2.3. Fuzzy TOPSIS

The TOPSIS model is one of the Multiple Attribute Decision Making (MADM) models that have been used for choosing the best alternative, as the other methods in MADM. The TOPSIS model was proposed by Hwang and Yoon [31] in 1981 and is one of the most widely used models of MADM [32-34]. TOPSIS offers the point, as the solution, that is, simultaneously, the farthest distance from the negation ideal and the nearest distance to the positive ideal [35]. In addition, when assessments are qualitative and linguistic variables are used, fuzzy TOPSIS can be suitable. In this regard, as in a realistic approach, we may use linguistic evaluation rather than numerical values, this technique can be used for six sigma project selection [36]. The TOPSIS method is considered a major MADM technique in comparison with other related techniques like AHP and ELECTRE [35,37,38]:

(i) It can include an unrestricted range of criteria and performance attributes;

(ii) It paves the way for explicit trade-offs and interactions among attributes. In other words, changes in one attribute can be neutralized by other attributes, in a direct or indirect manner;

(iii) It not only provides us with preferential ranking of alternatives, but also calculates a numerical value for each alternative for a better understanding of the differences and similarities between alternatives, while other MADM techniques (like ELECTRE) only determine the rank of alternative;

(iv) It avoids pair wise comparisons required by methods such as AHP. This method is especially useful when dealing with a large number of alternatives and criteria;

(v) It provides us with a systematic procedure, streamlined with a relatively simple computation process.

In this decision making method, it is assumed that K decision makers valuate m decision options or alternatives evaluated by n criteria [39]. The existing criteria are divided into two kinds, i.e. benefit (should be more) and cost (should be less) criteria [40]. Since most researchers that apply the Fuzzy TOPSIS method in their investigations use triangular fuzzy numbers [40,41], this paper has recognized its suitability, too. A triangular fuzzy number, $\tilde{A}$, defined by a triplet, $\tilde{A} = (a, b, c)$, and its membership function, are shown in Figure 1. For a more detailed and complete review of fuzzy set definitions, readers are referred to [31,41]. In this paper, as the problem has very complex, or not well defined conditions [41], we use the linguistic variables as defined in Table 1.

2.4. Allocating the six sigma projects

Six sigma projects are allocated to the relevant specialists, including black belts and green belts. Each project is assigned to a relevant expert, according to its importance and difficulty, and this stage is an important step in the success of six sigma projects [3,9]. Consequently, in this step, it is desired to allocate projects to qualified specialists, by considering the amount of effort (difficulty) and the impact of potential projects (important), that are allowed in order to postpone some projects.

2.4.1. Fuzzy expert system

From the previous decade, the use of expert systems (or knowledge-based systems) has extensively been

$$\mu_{\tilde{A}(x)} = \begin{cases} 0 & x < a \\ \frac{x-a}{b-a} & a \le x \le b \\ \frac{c-x}{c-b} & b \le x \le c \\ 0 & x > a \end{cases}$$

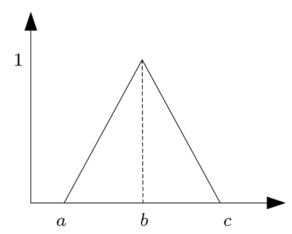

Figure 1. Triangular fuzzy number and the membership function [8].

Table 1. Linguistic variables and their corresponding triangular fuzzy numbers.

Linguistic variables for the ratings (Yong, 2006 [57]; Wang & Chang 2007 [63])		Linguistic variables for the relative importance weights of five criteria (Chu & Lin 2003 [39]; Chu 2002 [64])	
(0,0,1)	Very Poor (VP)	(0,0,0.1)	Very Low (VL)
(0,1,3)	Poor (P)	(0,0.1,0.3)	Low (L)
(1,3,5)	Medium Poor (MP)	(0.1,0.3,0.5)	Medium Low (ML)
(3,5,7)	Fair (F)	(0.3,0.5,0.7)	Medium (M)
(5,7,9)	Medium Good (MG)	(0.5,0.7,0.9)	Medium High (MH)
(7,9,10)	Good (G)	(0.7,0.9,1)	High (H)
(9,10,10)	Very Good (VG)	(0.9,1,1)	Very High (VH)

increased [42]. The main difference between expert systems and other software is that expert systems process knowledge, but other software processes data or information [43]. Expert systems provide a powerful, flexible method to solve various problems that cannot be solved by conventional methods [42]. The fuzzy expert decision support system is a type of expert system that uses fuzzy logic instead of Boolean logic (a complete system for logical operations). In other words, it uses fuzzy logic in its knowledge-base and deduces conclusions from user input and fuzzy inference processes [44]. Therefore, fuzzy rules and membership functions construct a knowledge-based system [42]. This means that a "fuzzy If-Then" rule is an "If-Then" rule, where some of its terms are denoted by continuous functions [45].

Fuzzy expert systems have been successfully applied to various real world applications, such as industrial process control, complex systems modelling and developing fuzzy inference systems [46,47]. Due to the widespread use of these systems, fuzzy inference systems are also known as fuzzy rule-based systems, fuzzy expert systems, fuzzy associative memories and fuzzy systems. All in all, a fuzzy system is composed of five components [48]:

- **Fuzzifier**: Converts the crisp inputs into degrees of match with linguistic values;
- **Dictionary**: Membership functions of the fuzzy sets used in the fuzzy rules are defined;
- **Fuzzy rule base**: Includes fuzzy If-Then rules with the dictionary and also the knowledge base of the fuzzy system;
- **Decision maker**: Performs inference operations on the rules;
- **Defuzzifier**: Transforms the fuzzy results of inference into a crisp output.

An expert system includes the following sections [42]:

a) **Fuzzy inference engine**: It is a program that analyzes the knowledge and rules aggregated in the database, and through this way, it finds the logical result. There are different choices for the fuzzy inference engine that depend on the aggregation, implication and the operators used for s-norm and t-norm [49].

b) **User interface**: The users of expert systems are organizational decision makers that log the real value of all linguistic variables by user interface. In addition, user interface exhibits index E for each six sigma project and uses MATLAB user interface to provide this aim in the designed system [42].

c) **Fuzzy rule base**: The fuzzy rule base provides a mechanism for building up the fuzzy rules which are conditional statements that can generally be represented by:

$$\text{If } x \text{ is } X_i \text{ and } y \text{ is } Y_i \text{ and } \cdots \text{ Then } o \text{ is } O_i, \quad (1)$$

where x and y are linguistic input variables, and linguistic values of X_i and Y_i are defined as possible linguistic values for x and y, respectively. Similarly, the decision variable or output, o, is a linguistic variable modelled as a fuzzy set with a possible value, O_i [42,50]. The knowledge representation in the form of rules, due to having a high modularity degree, paves the way for us to remove, add or amend easily [50].

Generally speaking, a fuzzy rule is an implication statement displayed with an If-Then rule in which the premise and the conclusion are fuzzy sets. The "If" part is the basic component, referring to the antecedent, and comes in initially. Subsequently, the "Then" part is usually mentioned (as, if antecedent, then, consequent) [48]. The antecedent can be a combination of a single condition or a set of conditions combined by a conjunction operator like "AND" and "OR". The rules have been settled once. In the next step, the matching degree of inputs with respect to fuzzy rules is determined for performing the inference process. If the problem includes multiple inputs, a conjunction operator will be used to combine the matching degree of the fuzzy inputs utilizing "max", "min", or "product" [51,52].

Several types of fuzzy system have been developed based on different tastes for the major blocks of a fuzzy system and various kinds of applications to which fuzzy systems are applied. Two types of fuzzy system that are commonly used are Mamdani fuzzy systems and Takagi-Sugeno-Kang (TSK) fuzzy systems [51,52]. They are applied in special fields due to their different abilities in different ways of knowledge representation. Mamdani fuzzy systems and TSK fuzzy systems are the same in some aspects, such as making fuzzy inputs and fuzzy operators. But, the main difference between these two methods is that the output of the TSK method is a member of functions that can be linear or constant, while, in the Mamdani inference, we expect the output to be a member of fuzzy sets [53]. In the design of the considered system in this paper, the TSK method is used based on expected results, although other types of fuzzy system, such as Tsukamoto fuzzy systems [54], ANFIS [55,56] etc., have their own particular applications. A comprehensive review on fuzzy systems can be found in [48,51,53].

3. Proposed framework for allocating and selecting the six sigma projects

The main purpose of this paper is to provide a framework for prioritizing and allocating the six sigma projects for implementing in industrial units. The steps of the presented framework are illustrated in Figure 2.

Step 1. *Selecting the most importance criteria*: This step should be performed, as the selection processes of six sigma project criteria are incomparable, and these criteria differ in various industrial units. In this step, those criteria that are more important than others in an industrial unit are prioritized and selected by the hypothesis test of the criteria mean for entering the third step. Hence, a survey is done from the viewpoint of six sigma implementation specialists, quality control personnel, quality assurance engineers, industrial specialists and experienced personnel of other departments of the organization who have a comprehensive perspective of their industrial units. It is better to equally select persons from different departments of an industrial unit; otherwise, selected criteria will tend towards the activities of a particular department.

Step 2. *Review of potential projects in the studied industrial units*: This step requires formation of a quality group in the organization. In this section, potential projects in industrial units are identified using criteria which have been examined in the literature.

Step 3. *Projects prioritization using fuzzy TOPSIS and determining the impact index for each project*: The inputs of this stage are potential projects (output stage 2) and important criteria in the industrial units (output stage 1). Project prioritization and final weight are named "Impact index", and are calculated by fuzzy TOPSIS. The utilized fuzzy TOPSIS method is proposed by Chen et al. [41] and Yong [57], and its assumptions are as follows:

- A committee of k decision-makers, $E = \{D_1, D_2, \cdots, D_k\}$;
- A set consists of m alternative, $A = \{A_1, A_2, \cdots, A_m\}$;
- A set consists of n criteria, $C = \{C_1, C_2, \cdots, C_n\}$, that measures the performance of alternatives;
- A set consists of the alternatives rating, $A_i(i = 1, 2, \cdots, m)$, with respect to criteria, $C_j(j =$

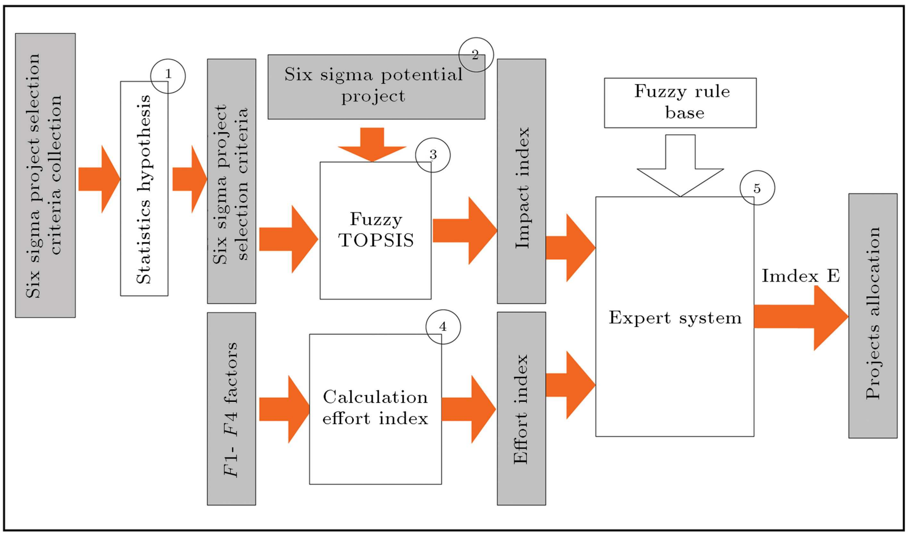

Figure 2. Proposed framework for prioritizing and allocating the six sigma projects.

$1, 2, \cdots, n)$, that is, $X = \{X_{ij}, i = 1, 2, \cdots m, j = 1, 2, \cdots n\}$.

In this section, it is assumed that we have K decision-makers and the fuzzy rating of any decision-maker, $D_k(k = 1, 2, \cdots, K)$, can be exhibited by triangular fuzzy numbers, $\tilde{R}_k(k = 1, 2, \cdots, K)$, with the membership function, $\mu_{\tilde{R}_k}(x)$. In other words, the fuzzy rating of all decision-makers is defined as:

$$\tilde{R} = (a, b, c), \quad k = 1, 2, 3, \cdots, K, \tag{2}$$

where, $a = \min_k \{a_k\}$, $b = \frac{1}{k} \sum_{k=1}^{k} b_k$, and $c = \max_k \{c_k\}$, and also fuzzy weight, $(\tilde{w}_j)$, of each criterion can be defined as follows:

$$\tilde{w}_j = (w_{j1}, w_{j2}, w_{j3}),$$

so that:

$$w_{j1} = \min_k \{w_{jk1}\}, \qquad w_{j2} = \frac{1}{k} \sum_{k=1}^{K} w_{jk2},$$

$$w_{j3} = \max_k \{w_{jk3}\}. \tag{3}$$

In general, a Multiple Criteria Decision Making (MCDM) problem can be expressed in the matrix format as follows:

$$\tilde{W} = [\tilde{w}_1, \tilde{w}_2, \cdots, \tilde{w}_n],$$

$$D = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}. \tag{4}$$

To avoid the complexity of mathematical operations in the decision making process, a linear transformation is used to ensure compatibility between the fuzzy evaluation values of all criteria, which must be converted into a compatible scale (into dimensionless indices). The criteria can be classified into benefit and cost criteria. Therefore, a normalized fuzzy-decision matrix can be expressed as $R = [\tilde{r}_{ij}]_{m \times n}$. In this equation, B and C are benefit and cost criteria, respectively.

$$\tilde{r}_{ij} = \left(\frac{\bar{a}_j}{c_{ij}}, \frac{\bar{a}_j}{b_{ij}}, \frac{\bar{a}_j}{a_{ij}} \right) j \in C, \qquad \bar{a}_j = \min_i a_{ij}, \tag{5}$$

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*} \right) j \in B, \qquad c_j^* = \max_i c_{ij}. \tag{6}$$

Considering the different importance of each criterion, a weighted normalized fuzzy-decision matrix is created as:

$$\tilde{V} = [\tilde{v}_{ij}]_{m \times n}, \qquad i = 1, 2, \cdots, m,$$

$$j = 1, 2, \cdots, m, \tag{7}$$

where $\tilde{\nu}_{ij} = \tilde{r}_{ij}.\tilde{w}_j$, and $\tilde{w}_j$ is the weight of the jth attribute or criterion. The Positive Ideal Solution (PIS) (A^*) and Negative Ideal Solution (NIS) (A^-) can be defined as:

$$A^* = (\tilde{v}_1^*, \tilde{v}_2^*, \cdots, \tilde{v}_n^*), \tag{8}$$

$$A^- = (\tilde{v}_1^-, \tilde{v}_2^-, \cdots, \tilde{v}_n^-). \tag{9}$$

If $\tilde{m} = (m_1, m_2, m_3)$ and $\tilde{n} = (n_1, n_2, n_3)$ are two triangular fuzzy numbers, the distance between them can be calculated using the maximum height as follows [41]:

$$d_v(\tilde{m}, \tilde{n}) = \sqrt{\frac{1}{3}\left[(m_1 - n_1)^2 + (m_2 - n_2)^2 + (m_3 - n_3)^2\right]}. \tag{10}$$

Consequently, the distance of each alternative from A^* and A^- is calculated, respectively, as follows:

$$d_i^* = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^-), \qquad i = 1, 2, \cdots, m, \tag{11}$$

$$d_i^- = \sum_{j=1}^{n} d_v(\tilde{v}_{ij}, \tilde{v}_j^-), \qquad i = 1, 2, \cdots, m. \tag{12}$$

At the end, relative closeness is used for ranking the alternatives. This index considers PIS and NIS simultaneously. Consequently, an alternative should be chosen that is closer to PIS and farther from NIS.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-}, \tag{13}$$

$$i = 1, 2, \cdots, m, \qquad 0 \le CC_i \le 1.$$

The alternatives are ranked according to the relative closeness. The best alternatives are those that have higher value.

Step 4. *Calculating the effort index of projects*: To determine criteria that have the Effort concept for the projects, the eight six sigma experts (graduates having 5 years experience in six sigma projects) are asked to introduce those factors that have the Effort concept for the six sigma projects. After sending and receiving the questionnaire three times, four criteria, i.e. project scope, F_1, availability of resources, F_2, needed time, F_3, and ability to access information, F_4, were selected.

F_2 and F_4 criteria have a positive context and F_1 and F_3 are negative criteria. Positive criteria mean that a higher value is better, while negative criteria are vice versa. The purpose of Effort index determination is evaluation of the effort required for implementing six sigma projects. Therefore, the Effort index can be considered a negative concept. In this regard, if a project needs less effort, it will be allocated to less expert persons, i.e. green belts, and if a project requires more effort, it will be allocated to more expert persons, i.e. black belts.

For converting F_2 and F_4 criteria that are positive criteria, Table 1 is used for the fuzzy values. Also, the fuzzy values of F_1 and F_3 criteria that are negative criteria are obtained as VL = (0,0,1), L = (0,1,3), ML = (1,3,5), (3, 5,7) = M, MH = (5,7,9), H = (7,9,10) and VH = (9,10,10). The normalized value of numbers can be expressed as:

$$R = [\tilde{r}_{ij}]_{m\times n}. \tag{14}$$

In this regard, B and C are the benefit and cost criteria in order, and can be obtained as:

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{C_j^*}, \frac{b_{ij}}{C_j^*}, \frac{C_{ij}}{C_j^*}\right) \qquad j \in B, \quad C_j^* = \max_i C_{ij}, \tag{15}$$

$$\tilde{r}_{ij} = \left(\frac{10 - C_{ij}}{C_j^*}, \frac{10 - b_{ij}}{C_j^*}, \frac{10 - a_{ij}}{C_j^*}\right) \qquad j \in C,$$

$$C_j^* = \max_i C_{ij}. \tag{16}$$

Then, after normalizing the criteria, the 'Effort index' is calculated, according to Eq. (17). In this equation, the weights of criteria are considered differently. In addition, if their weights are considered equal, the Effort index can be evaluated from Eq. (18):

$$\text{Effort index} = \frac{\sum_{j=1}^{4} w_i f_i}{\sum_{j=1}^{4} w_i}, \qquad \sum_{j=14}^{4} w_i = 1, \tag{17}$$

$$\text{Effort index} = \frac{\sum_{j=1}^{4} f_i}{4}. \tag{18}$$

Finally, after calculating the Effort index, it should be defuzzified into a crisp value for input to a fuzzy expert system, and can be obtained as:

$$\text{Effort index} = (a, b, c) \xrightarrow{\text{defuzzy}} \frac{(a + 4b + c)}{6}. \tag{19}$$

Step 5. *Allocation of six sigma projects using fuzzy expert system*: The TSK fuzzy system was developed as a systematic approach for generating fuzzy rules from a given input-output data set [48]. The rules of this fuzzy system are defined as [48,52]:

$$\text{If } x_1 \text{ is } A_1 \text{ AND/OR } x_2 \text{ is } A_2 \text{ then } y = f(x_1, x_2), \tag{20}$$

where A_1 and A_2 are fuzzy sets and y is a function (usually linear) of crisp variables. In order to perform inference operations, the output of each rule should be weighted. For instance, the jth rule is calculated as:

$$R_j\text{: If } x_1 \text{ is } A_j \text{ AND } x_2 \text{ is } B_j \text{ then } y_j = f_j(x_1, x_2). \tag{21}$$

The weight, w_j, is calculated as w_j=AND method $(\mu_{A_j}(X_1), \mu_{B_j}(X_2))$, and where $\mu_{A_j}(.)$ and $\mu_{B_j}(.)$ are considered membership functions of A_j and B_j, respectively, and the AND method is an operation defined by the AND operator that is usually the "min" operation. In this regard, if we consider the effect of rules to be the same, w_j will be equal to one for all the rules. The final output of the system will be calculated as [48]:

$$\text{Final output} = \sum_j w_j y_j / \sum_j w_j. \tag{22}$$

Fuzzy systems make decisions and generate output values based on knowledge that were provided by the designer in the form of If-Then rules [14]. The rule base qualitatively specifies how the output parameter of the six sigma project is determined for various instances of the input factors. The principles of the following rules were extracted from the research of Snee (2002) [9], Dickman & Doran (2003) [10], and Yang & Heshin (2009) [13]. These principles are stabilized on the basis of projects being selected and prioritized according to their importance to the company [1,58], and whichever projects are too difficult should be allocated to more qualified specialists [3]. Subsequently, the rules are defined as:

1. If (Impact index is **VL**) and (Effort index is **VL**) then (Index ES is **VL**);
2. If (Impact index is **VL**) and (Effort index is **L**) then (Index ES is **VL**);
3. If (Impact index is **VL**) and (Effort index is **M**) then (Index ES is **VL**);
4. If (Impact index is **VL**) and (Effort index is **H**) then (Index ES is **L**);
5. If (Impact index is **VL**) and (Effort index is **VH**) then (Index ES is **L**);
6. If (Impact index is **L**) and (Effort index is **VL**) then (Index ES is **L**);
7. If (Impact index is **L**) and (Effort index is **L**) then (Index ES is **L**);
8. If (Impact index is **L**) and (Effort index is **M**) then (Index ES is **L**);
9. If (Impact index is **L**) and (Effort index is **H**) then (Index ES is **VL**);
10. If (Impact index is **L**) and (Effort index is **VH**) then (Index ES is **VL**);

11. If (Impact index is **M**) and (Effort index is **VL**) then (Index ES is **M**);
12. If (Impact index is **M**) and (Effort index is **L**) then (Index ES is **M**);
13. If (Impact index is **M**) and (Effort index is **M**) then (Index ES is **M**);
14. If (Impact index is **M**) and (Effort index is **H**) then (Index ES is **H**);
15. If (Impact index is **M**) and (Effort index is **VH**) then (Index ES is **H**);
16. If (Impact index is **H**) and (Effort index is **VL**) then (Index ES is **M**);
17. If (Impact index is **H**) and (Effort index is **L**) then (Index ES is **M**);
18. If (Impact index is **H**) and (Effort index is **M**) then (Index ES is **M**);
19. If (Impact index is **H**) and (Effort index is **H**) then (Index ES is **H**);
20. If (Impact index is **H**) and (Effort index is **VH**) then (Index ES is **VH**);
21. If (Impact index is **VH**) and (Effort index is **VL**) then (Index ES is **M**);
22. If (Impact index is **VH**) and (Effort index is **L**) then (Index ES is **M**);
23. If (Impact index is **VH**) and (Effort index is **M**) then (Index ES is **M**);
24. If (Impact index is **VH**) and (Effort index is **H**) then (Index ES is **H**);
25. If (Impact index is **VH**) and (Effort index is **VH**) then (Index ES is **VH**) .

Sensitive analysis of a fuzzy expert system for six sigma project allocation is illustrated in Figure 3.

Expert system output (ES index) is a crisp value with a range between 0 and 1, and is used for decision making about project allocation, as illustrated in Figure 4. This range is divided into three segments:

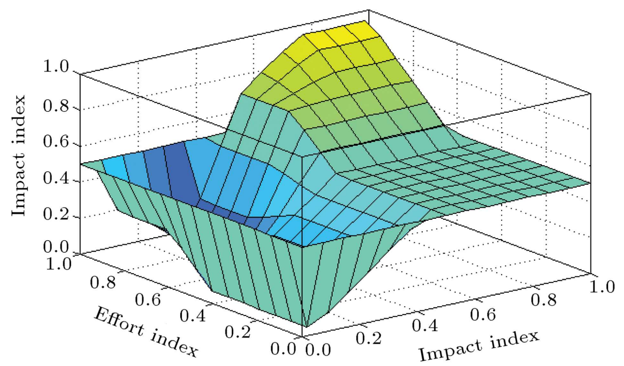

Figure 3. The sensitive analysis of fuzzy expert system for six sigma project allocation.

Figure 4. The ranges of index ES and decision making about its different values.

i) Projects whose ES index is less than a will either be given up or postponed for consideration in future projects;

ii) Projects whose ES index is between α and β will be allocated to green belts;

iii) Projects whose ES index is more than β will be allocated to black belts.

The deterministic value of a and β are not the same for all companies; some factors, such as the expertise level of six sigma professionals, the experience of the company in six sigma project implementation, the number of six sigma professionals etc. are all effective in determination of the values of a and β. Consequently, these parameters should be specified in each company depending on its situation. It is clear that the implementation sequence of projects is on the basis of fuzzy TOPSIS ranking. The projects that are not executable at this step are sent to the second step for review.

Finally, by allocating projects to specialists, the work begins with the project charter (project description) [6,59,60], and, by using the framework presented in this paper, one can be confident of effective and efficient project implementation by the appropriate six sigma specialists.

4. Case study

This company is one of the top suppliers of Iran Khodro Co. (IKCo). In the first step of the presented framework, the most important criteria were considered in this industrial unit. In this regard, a questionnaire was distributed among 40 employees (engineers, managers of production units, six sigma specialists including Green Belts and Black Belts, quality assurance specialists and quality control experts). The response rate was 80 percent. The validity of the questionnaire, according to criteria, such as, availability of resources, direct relationship with strategic objectives, project scope etc., which were obtained from literature, were investigated and confirmed. The questions of the questionnaire are on the basis of the Likert Scale (a five options range). The reliability of the questionnaire was calculated using Cronbach's alpha ($\alpha = 0.754$).

Owing to the fact that the criteria whose importance is greater than average are considered, relation ($H_0 : \mu_i \leq 3, H_1 : \mu_i > 3$) is used for selecting the criteria with above-average importance.

In the test of hypothesis about the mean, a t-test at the level of significance 0.05, with Degree Of

Table 2. Statistical test results.

Criteria	Test value	t	n	Sig. (2-tailed)	95% confidence interval of the difference	
					Lower	Upper
Availability of resources	3	0.758	32	0.454*	-0.2559	0.5589
The investment return	3	-2.248	32	0.032	-0.6932	-0.0341
Special needs to improve	3	0.611	32	0.545*	-0.2827	0.5251
Employees satisfaction from projects	3	-2.516	32	0.017	-0.7128	-0.0751
Needed time	3	4.945	32	0.000*	0.4812	1.1552
Project scope	3	-4.690	32	0.000	-0.9562	-0.3771
Financial efficiency-increasing profits	3	0.197	32	0.845*	-0.2829	0.3435
Direct relation with the strategic objectives	3	6.128	32	0.000*	0.5665	1.1305
Measurability	3	-2.935	32	0.006	-0.7187	-0.1298
Customer satisfaction	3	-2.782	32	0.009	-0.7873	-0.1218
The relation with the key processes of the organization	3	0.463	32	0.647*	-0.3091	0.4909
Ability to access information	3	-2.603	32	0.014	-0.7563	-0.0922

Freedom $n-1$, is investigated. This test was done on each question of the questionnaire and the results are shown in Table 2. Decision making about the statistical assumptions in SPSS16 software is on the basis of value Sig. (Significance or P-value). Also, in these tests of hypothesis, if the value of Sig. is more than 0.05, H_0 is not rejected [61].

Totally, for the six criteria that are more important than others, as cited by the respondents in this industrial unit, a statistical calculation was performed, including availability of resources, special needs to improve, and financial efficiency-increasing profits, and the relation with the key processes of the organization, i.e. needed time and direct relation with the strategic objectives (owing to the fact that both lower and upper limits of these criteria are positive, and their averages are certainly more than 3 [62]). These criteria will be used for prioritizing the six sigma project by the fuzzy TOPSIS method.

4.1. Selecting the six sigma potential projects

At this step, for selecting the six sigma potential projects, the projects initial study is discussed in the studied company. In this context, at first, potential projects, which have been extracted from assessment reports of customer satisfaction, employee suggestions, competitor analysis, the amount of waste costs and the results of Cost Of Quality (COQ), are superficially considered by quality control and quality assurance personnel of the company. After preliminary screening, six sigma projects; A_1 (reduce internal PPM (Part Per Million) of rocker arm), A_2 (power steering system structural problems), A_3 (low-quality of Peugeot 405 tappet), A_4 (power steering system losses from external logistics), A_5 (long process of responding to non conformity of SAPCO (the only customer of the company)) and A_6 (reduce cycle time of raw material preparation), are chosen for further evaluation.

4.2. Ranking the six sigma projects using fuzzy TOPSIS

Six potential projects (A_1, A_2, A_3, A_4, A_5 and A_6) have been selected for prioritization. These projects each have some strengths and weaknesses. For prioritizing the six sigma projects, six criteria are: Direct relation with the strategic objectives are (C_1), the relation with the key processes of the organization (C_2), financial efficiency-increasing profits (C_3), special needs to improve (C_4), needed time (C_5), and availability of resources (C_6). The C_1, C_2, C_3, C_4 and C_6 are benefit criteria and C_5 is cost criteria. The benefit criterion means that a higher value is better, while, for the cost criterion, the opposite is valid. A committee of three decision-makers, D_1, D_2 and D_3, who are experienced and experts in quality control, and six sigma projects (having graduate degrees and over 5 years experience in six sigma implementation) are used to assess the importance of the criteria, as shown in Table 3.

Table 3. The importance weight of the criteria.

Criteria	Decision makers			Average of weights
	D_1	D_2	D_3	
C_1	ML	ML	M	(0.03, 0.17, 0.37)
C_2	H	H	H	(0.50, 0.70, 0.90)
C_3	VH	VH	H	(0.63, 0.83, 0.97)
C_4	L	ML	L	(0.00, 0.03, 0.17)
C_5	VH	MH	H	(0.50, 0.70, 0.87)
C_6	H	H	VH	(0.57, 0.77, 0.93)

Table 4. Fuzzy decision making matrix and their fuzzy weights.

	C_1	C_2	C_3	C_4	C_5^-	C_6
LV	(0.03, 0.17, 0.37)	(0.50, 0.70, 0.90)	(0.63, 0.83, 0.97)	(0.00, 0.03, 0.17)	(0.50, 0.70, 0.87)	(0.57, 0.77, 0.93)
A_1	(0.33, 1.67, 3.67)	(4.33, 6.33, 8.33)	(7.67, 9.33, 10.0)	(3.00, 5.00, 7.00)	(0.33, 1.67, 3.67)	(4.33, 6.33, 8.33)
A_2	(1.67, 3.67, 5.67)	(6.33, 8.33, 9.67)	(5.67, 7.67, 9.33)	(0.00, 0.33, 1.67)	(1.67, 3.67, 5.67)	(5.67, 7.67, 9.33)
A_3	(9.00, 10.00, 10.0)	(3.67, 5.67, 7.67)	(5.67, 7.67, 9.33)	(4.33, 6.33, 8.33)	(2.33, 4.33, 6.33)	(3.00, 5.00, 7.00)
A_4	(0.00, 1.00, 3.00)	(3.67, 5.67, 7.67)	(9.00, 10.00, 10.0)	(5.00, 7.00, 9.0)	(2.33, 4.33, 6.33)	(0.00, 0.67, 2.33)
A_5	(2.33, 4.33, 6.33)	(0.33, 1.67, 3.67)	(8.33, 9.67, 10.0)	(6.33, 8.33, 9.67)	(6.33, 8.33, 9.67)	(0.67, 2.33, 4.33)
A_6	(6.33, 8.33, 9.67)	(0.00, 0.00, 1.00)	(8.33, 9.67, 10.0)	(4.33, 6.33, 8.33)	(1.67, 3.67, 5.67)	(8.33, 9.67, 10.0)

Table 5. Weighted normalized fuzzy-decision matrix.

	C_1	C_2	C_3	C_4	C_5^-	C_6
A_1	(0.00, 0.03, 0.13)	(0.22, 0.46, 0.78)	(0.49, 0.78, 0.97)	(0.00, 0.02, 0.12)	(0.05, 0.14, 0.08)	(0.25, 0.49, 0.78)
A_2	(0.01, 0.06, 0.21)	(0.33, 0.60, 0.90)	(0.36, 0.64, 0.90)	(0.00, 0.00, 0.03)	(0.03, 0.06, 0.05)	(0.32, 0.59, 0.87)
A_3	(0.03, 0.17, 0.37)	(0.19, 0.41, 0.71)	(0.36, 0.64, 0.90)	(0.00, 0.02, 0.14)	(0.03, 0.05, 0.05)	(0.17, 0.38, 0.65)
A_4	(0.00, 0.02, 0.11)	(0.19, 0.41, 0.71)	(0.57, 0.83, 0.97)	(0.00, 0.02, 0.16)	(0.03, 0.05, 0.05)	(0.00, 0.05, 0.22)
A_5	(0.01, 0.07, 0.23)	(0.02, 0.12, 0.34)	(0.53, 0.81, 0.97)	(0.00, 0.03, 0.17)	(0.02, 0.03, 0.03)	(0.04, 0.18, 0.40)
A_6	(0.02, 0.14, 0.35)	(0.00, 0.00, 0.09)	(0.53, 0.81, 0.97)	(0.00, 0.02, 0.14)	(0.03, 0.06, 0.05)	(0.47, 0.74, 0.93)

Table 6. Positive and negative ideal solutions.

	C_1	C_2	C_3	C_4	C_5^-	C_6
A^*	(0.37, 0.37, 0.37)	(0.90, 0.90, 0.90)	(0.97, 0.97, 0.97)	(0.17, 0.17, 0.17)	(0.14, 0.14, 0.14)	(0.93, 0.93, 0.93)
A^-	(0.00, 0.00, 0.00)	(0.02, 0.02, 0.02)	(0.36, 0.36, 0.36)	(0.00, 0.00, 0.00)	(0.02, 0.02, 0.02)	(0.00, 0.00, 0.00)

Also, the decision-makers use the linguistic weighting variables (as shown Table 1) to assess the importance of the criteria. The decision-makers ratings regarding all criteria to alternatives were collected in the form of linguistic variables and changed to fuzzy numbers with an average of rating, as shown in Table 4. The needed time criterion is a cost criterion, so it is vice versa to other criteria. Linguistic variables for the importance weight of this cost criterion is considered as VL = (0,0,1), L = (0,1,3), ML = (1,3,5), M = (3,5,7), MH = (5,7,9), H = (7,9,10) and VH = (9,10,10) [41].

The decision matrix is normalized and then is calculated by the product weight of criteria, according to Eq. (7), and the results are presented in Table 5. Then, positive and negative ideal solutions are calculated according to Eqs. (8) and (9), and the results are illustrated in Table 6. In the next step, the distances from the positive and negative ideal solutions of each alternative, using Eqs. (10), (11) and (12), are calculated and the results have been illustrated in Table 7.

Finally, for ranking the projects, the relative closeness as mentioned in Eq. (13) is used to calculate the final weights. The results are calculated and reported in Table 7. Alternative prioritization based on their weight is as $A_2 > A_1 > A_3 > A_6 > A_4 > A_5$.

Table 7. The distance of the alternatives from the positive and negative ideals, their final weights and ranks.

Alternatives	d^+	d^-	$d^+ + d^-$	Final weight	Rank
A_1	1.77	1.747	3.514	0.497	2
A_2	1.72	1.816	3.535	0.514	1
A_3	1.93	1.633	3.563	0.458	3
A_4	2.15	1.260	3.414	0.369	5
A_5	2.28	1.159	3.443	0.337	6
A_6	1.89	1.578	3.467	0.455	4

4.3. Allocating the projects

At this stage, in order to allocate the projects to six sigma professionals, two index, impact and effort, are used, respectively, which are the calculated weights from the output of the TAPSIS method and required attempts for each project, and they are calculated as follows.

In this regard, three experts, D_1, D_2 and D_3, were considered six projects on the basis of four criteria (project scope F_1, availability of resources F_2, needed time F_3 and ability to access information F_4). Their ideas were collected with linguistic variables and changed to fuzzy numbers, and their final ideas are the mean of their ideas normalized, according to

Table 8. Make decision normalized matrix.

	F_1	F_2	F_3	F_4
A_1	(0.23, 0.43, 0.63)	(0.17, 0.37, 0.57)	(0.03, 0.17, 0.37)	(0.77, 0.93, 1.00)
A_2	(0.77, 0.93, 1.00)	(0.07, 0.23, 0.43)	(0.17, 0.37, 0.57)	(0.63, 0.83, 0.97)
A_3	(0.77, 0.93, 1.00)	(0.30, 0.50, 0.70)	(0.23, 0.43, 0.63)	(0.00, 0.03, 0.17)
A_4	(0.07, 0.23, 0.43)	(0.77, 0.93, 1.00)	(0.23, 0.43, 0.63)	(0.17, 0.37, 0.57)
A_5	(0.00, 0.03, 0.17)	(0.57, 0.77, 0.93)	(0.63, 0.83, 0.97)	(0.00, 0.03, 0.17)
A_6	(0.23, 0.43, 0.63)	(0.00, 0.03,0.17)	(0.17, 0.37,0.57)	(0.30, 0.50,0.70)

Table 9. The value of impact and effort for each alternative.

Projects	e	Effort index	Impact index	Index ES	Projects allocation results
A_1	(0.30, 0.48, 0.64)	0.4736	0.497	0.496	Green belt
A_2	(0.41, 0.59, 0.74)	0.585	0.514	0.606	Black belt
A_3	(0.33, 0.48, 0.63)	0.4750	0.458	0.448	Green belt
A_4	(0.31, 0.49, 0.66)	0.4889	0.369	0.336	Give up or postpone
A_5	(0.30, 0.42, 0.56)	0.4208	0.337	0.296	Give up or postpone
A_6	(0.18, 0.33, 0.52)	0.3375	0.455	0.444	Green belt

Figure 5. The ranges of index ES in case study.

Eq. (5), and the results are illustrated in Table 8. In this section, all the criteria have been converted to a negative concept.

Now, the fuzzy value of effort index (e) can be calculated using Eq. (18) whose results are presented in Table 9. Finally, the crisp values of the effort index are defuzzified, using Eq. (19), and illustrated in Table 9, with the respective impact indexes that are outputs of fuzzy TOPSIS.

The ranges of decision making on expert system output, in this instance, according to quality control experts of the company and previous successful projects, are illustrated in Figure 5.

In addition, the two indexes, obtained (Error index and Impact index) are the inputs of the fuzzy expert system, and the output results (index ES) of that with decision making, regarding the allocation of each project, are illustrated in Table 9. According to that, the A_2 project is allocated to more experienced specialists called Black Belts. Projects A_6, A_1 and A_3 are assigned to the Green Belts. Also, Projects A_4 and A_5, due to their low impact for the company, will not be undertaken or will be delayed until they are checked with other projects the next time. Of course, this step is for allocating projects to specialists, and the implementation sequence of the projects are according to the output of the TOPSIS method, namely $A_2 > A_1 > A_3 > A_6 > A_4 > A_5$.

5. Conclusion and suggestions for future research

Six sigma is considered a quality improvement approach including waste reduction and income earning. One of the most important stages in implementing a six sigma project is the SSPS stage. The purpose of this paper is to develop a new model for identifying effective projects in an organization and allocating them to project specialists. In this paper, using a step by step model, firstly, all the criteria for six sigma project allocation are considered and the most important are identified. Then, the impact index, which is the output of the TOPSIS method, and the effort index are calculated. In addition, using a fuzzy expert system, the six sigma projects are allocated to the relevant specialist. So, it can be claimed that two indexes, Impact and Effort, are used for allocating the six sigma potential projects to a six sigma specialist.

To calculate the impact index, the important criteria are: availability of resources, needed time, direct relation with strategic objectives, the relation with the key processes of the organization, financial efficiency-increasing profits, and special needs to improve. In the presented case study, the direct relation with the strategic objective criterion was identified as being the most important. Availability of resources, needed time, project scope and ability to access information are criteria that are used for calculation of the Effort index. In the case study, these criteria are considered with the assumption of equal weight. Of course, these criteria have different importance, according to the terms. According to the implemented survey in the case study, the direct relation with the strategic objectives, financial efficiency-increasing profits and needed time are the most important criteria in six sigma project selection and prioritization. The Impact index and the Effort index, respectively, are effective on the prioritization and allocation of six sigma projects. Of course, the Impact index has more importance in decision making owing to a lack of some project implementations. Further work can focus on determination of α and β in the expert system output. Also, this framework can be used as a basic pattern for developing new models in other industries, and the most important criteria in the prioritization and allocation of six sigma projects can be identified in these industries.

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