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Selecting Six Sigma projects: MCDM or DEA?

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1. Introduction

Six sigma is an innovative method and improves strategically the business. It is a customer-based, orderly, advantageous and systematically optimizing method which encompasses the whole organization, is based on measurable methodology and focuses steadily upon the process. Six sigma utilizes statistical methods and the principles of quality management to optimize processes and products. It is done by Defining, Measuring, Analyzing, Improving and Controlling (DMAIC) the framework of quality improvement and based on a project-to-project process to meet the customers' needs [1,2].

In recent years, manufacturing organizations succeeded in utilizing six sigma as a strategy to reduce the numbers of defective units in the manufacturing process, consequently reducing the costs and increasing the profits [3]. It has been reported the advantages of six sigma in the related literatures [4-8]. However, there are considerable cases in which the six sigma has failed in producing the expected results. The results from a research by the journal "Aviation Week" among the major aerospace companies showed that about 50% of these companies were satisfied with the results of six sigma projects, 30% of them were unsatisfied, and nearly 20% of them were partially satisfied [9]. Yet, comparing with the process optimizing techniques used in recent five decades, six sigma has emerged evidently as the most influential technique in quality optimizing [10].

Six sigma is developed from the previous quality methods such as total quality management (TQM), deeming statistical quality control. Six sigma can be defined as a strategy, involving TQM, strong focus on customers, enhanced tools for analyzing data, financial results and project management [11,12]. Although, it is originated from the manufacturing organizations and intended to reduce defects in producing process, nowadays, all industries utilize six sigma, including service industries such as healthcare management [13-16]. Contrary to potential of six sigma in extensive applications, none of other quality improvement initiatives has gained such high application outside the manufacturing organizations.

The question is not if to use six sigma, but how to execute successfully a six sigma process optimizing project. Probably the most difficult step in six sigma is to select a process optimizing project [17,18]. Most of debates in six sigma literatures are devoted to selecting six sigma projects [19,20]. It necessitates various resources to implement a six sigma project, such as investments and manpower (in the form of green and black belts). Based on these resources, a successful six sigma project can reveal useful outputs in the form of enhancing the quality level of six sigma, increasing customer's satisfaction, reducing cost of poor quality (COPQ). Table 1 lists the tools used to select a six sigma project.

Table 1. Methods used to select a six sigma project

Three techniques are used in this paper in order to select six sigma optimized projects. They are Analytic Hierarchy Process (AHP), the Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS), and Data Envelopment Analysis (DEA). Among them, AHP and TOPSIS are the most important techniques of Multi Criteria Decision Making (MCDM). These two techniques are based on weighting the selection criteria by decision maker. Weighting in AHP is performed by comparing the dual pair of selected criteria. The weights obtained by AHP for criteria are used also in TOPSIS. In DEA, unlike two previous models, decision maker don't weight the criteria, but the model does it so that every Decision Making Unit (DMU) gains its highest possible efficiency. In fact, DEA is a technique for measuring the relative efficiency of each DMU, and it is done by calculating the ratio of homogenous sum of output criteria to input ones. Since this efficiency is a good indicator for recognizing the optimized units, DEA is used to select the optimized projects in this paper.

The rest of this paper unfolds as follows. The most important criteria for selecting six sigma projects are reviewed in section 2. The utilized techniques are presented in section 3. Besides, in this section a new DEA model is proposed to evaluate the relative efficiency of six sigma projects. Section 4 is covered

Comparing and determining the importance of criteria for selecting a six sigma project. Section 5 is devoted to an illustrative numerical example. Discussion and conclusions are given in section 6.

2. Defining criteria for selecting the six sigma project

Selecting a proper six sigma project demands precise analyses. The selected project must be orientated to strategic goals of organization. Pande et al. [17] categorized the criteria for six sigma project as follows:

- 1- Advantages of the project for business
- 2- Accessibility to the project
- 3- Influence of the project on the organization.

Advantages of the project for business include influence upon the customer, influence upon the strategy of business, influence upon the major competencies, financial and immediate influences. The criteria for accessibility to a six sigma project are: needed resources, expertise in access, complexity, possibility to success. Learning and cross-responsibility are discussed under the influences of the project on the organization.

Harry and Schroeder [37] propose the following criteria for a six sigma project:

- 1- Defeat per million opportunities (DPMO)
- 2- Pure savings in costs
- 3- Costs of poor quality (COPQ)
- 4- Period of cycle
- 5- Customer's satisfaction
- 6- Capacity
- 7- Internal performance

Banuelas et al. [21] indicated the following six criteria for a six sigma project:

- 1- Influence upon the customers
- 2- Financial influences
- 3- Top management commitment
- 4- Measurability and accessibility
- 5- Development and learning
- 6- Link to strategy of business and competency

It is obvious in research literatures that it is a multi criteria decision making to select a six sigma project. Here we consider six criteria which are mostly used in research literatures as ones to select a six sigma project :

- 1- Cost of project (Cost)
- 2- Drop-off in costs due to poor quality (COPQ)
- 3- Duration of executing the project (Time)
- 4- Customer's satisfaction (Customer)
- 5- Increasing the sigma level (Sigma)
- 6- Responsibility of top management (Top Mngr)

Fig.2 depicts ranking and importance degree of criteria that is resulted from pairwise assessments. Base on the figure2, Top Mngr, Customer, and COPQ are the three most preferred criteria, respectively. Sigma, Cost, and time, are placed in forth to sixth priorities, respectively. Note that model can vary according to the decision maker's vision by adding or eliminating some of criteria.

3. Utilized techniques

3. 1. Analytic Hierarchy Process (AHP)

AHP is developed by Saaty [31], probably the best-known and most widely used model in decision making. AHP is a powerful decision making methodology in order to determine the priorities among different criteria. The AHP encompasses six basic steps as summarized as follows:

Step 1. AHP uses several small sub-problems to present a complex decision problem. Thus, the first act is to decompose the decision problem into a hierarchy with a goal at the top, criteria and sub-criteria at levels and sub-levels of and decision alternatives at the bottom of the hierarchy (Fig. 1).

Fig.1. The hierarchical structure of the decision making problem

Step 2. The decision matrix, which is based on Saaty's nine-point scale, is constructed. The decision maker uses the fundamental 1–9 scale defined by Saaty to assess the priority score. In this context, the assessment of 1 indicates equal importance, 3 moderately more, 5 strongly more, 7 very strongly and 9 indicates extremely more importance. The values of 2, 4, 6, and 8 are allotted to indicate compromise values of importance. In this paper this definition has been changed a little (Table 2).

Table 2. The numerical assessments and their linguistic meanings

The decision matrix involves the assessments of each alternative in respect to the decision criteria. If the decision making problem consists of n criteria and m alternatives; the decision matrix takes the form:

$$D = \begin{bmatrix} d_{11} & d_{12} & \dots & d_{1n} \\ d_{21} & d_{22} & \dots & d_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ d_{m1} & d_{m2} & \dots & d_{mn} \end{bmatrix} \quad (1)$$

The elements $\{d_{ij}\}$ signify the rating of the i th alternative in respect to the j th criteria.

Step 3. The third step involves the comparison in pairs of the elements of the constructed hierarchy. The aim is to set their relative priorities with respect to each of the elements at the next higher level. The pairwise comparison matrix, which is based on the Saaty's 1–9 scale, has the form:

$$\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix} \quad (2)$$

Where w_i is the weight of the i th element. If $n(n-1)/2$ comparisons are consistent with n is the number of criteria, then the elements $\{a_{ij}\}$ will satisfy the following conditions: $a_{ij} = w_i / w_j = 1 / a_{ji}$ and $a_{ii} = 1$ with $i, j, k = 1, 2, \dots, n$.

In the comparison matrix, a_{ij} can be interpreted as the degree of preference of i th criteria over j th criteria. It appears that the weight determination of criteria is more reliable when using pairwise comparisons than obtaining them directly, because it is easier to make a comparison between two attributes than make an overall weight assignment.

Step 4. AHP also calculates an inconsistency index (or consistency ratio) to reflect the consistency of decision maker's judgments during the evaluation phase. The inconsistency index in both the decision matrix and in pairwise comparison matrices could be calculated with the equation:

$$CI = \frac{\lambda_{\max} - N}{N - 1} \quad (3)$$

λ_{\max} and N are the highest eigenvalue and the number of criteria, respectively. The closer the inconsistency index is to zero, the greater the consistency. The consistency of the assessments is ensured if the equality $a_{ij} \cdot a_{jk} = a_{ik}$ holds for all criteria. The relevant index should be lower than 0.10 to accept the AHP results as consistent. If this is not the case, the decision-maker should go back to Steps 2 and 3 and redo the assessments and comparisons.

Step 5. Before all the calculations of vector of priorities, the comparison matrix has to be normalized. Therefore, each column has to be divided by the sum of entries of the corresponding column. In that way, a normalized matrix is obtained in which the sum of the elements of each column vector is 1.

Step 6. For the following part, the eigenvalues of this matrix are needed to be calculated which would give the relative weights of criteria. This procedure is common in mathematics; however we have used the Expert Choice software, that is a multi-objective decision support tool. The relative weights obtained in the third step should verify

$$A \cdot W = \lambda_{\max} \cdot W \quad (4)$$

where A represents the pairwise comparison matrix, W the eigenvector and λ_{\max} the highest eigenvalue. If there are elements at the higher levels of the hierarchy, the obtained weight vector is multiplied with the weight coefficients of the elements at the higher levels, until the top of the hierarchy is reached. The alternative with the highest weight coefficient value should be taken as the best alternative [32].

3. 2. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS method, which is based on choosing the best alternative having the shortest distance to the ideal solution and the farthest distance from the negative-ideal solution, was first proposed in 1981 by Hwang and Yoon [33]. The ideal solution is the solution that maximizes the benefit and also minimizes the total cost. On the contrary, the negative-ideal solution is the solution that minimizes the benefit and also maximizes the total cost.

For the first step of this methodology, the decision matrix, representing the performance values of each alternative with respect to each criterion, is computed. Next, these performance values are multiplied with the criteria weights calculated with AHP. The step of defining the ideal solution consists of taking the best values of alternatives and with the similar principle, the negative-ideal solution is obtained by taking the worst values of alternatives. Subsequently, the alternatives are ranked with respect to their relative closeness to the ideal solution.

The TOPSIS procedure consists of the following steps:

Step 1. The first step of the procedure involves the calculation of the normalized decision matrix. The normalized value $\{r_{ij}\}$ is calculated as

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^J f_{ij}^2}}, \quad j = 1, \dots, J; \quad i = 1, \dots, n. \quad (5)$$

Where J is the number of alternatives and n is the number of criteria.

Step 2. In the next step, the weighted normalized decision matrix is calculated. The weighted normalized value v_{ij} is calculated as

$$v_{ij} = w_i \times r_{ij}, \quad j = 1, \dots, J; \quad i = 1, \dots, n, \quad (6)$$

where w_i is the weight of the i th criterion, and $\sum_{i=1}^n w_i = 1$.

Step 3. In this step, the ideal and negative-ideal solutions are determined.

$$A^+ = \{v_1^+, \dots, v_n^+\} = \left\{ \left(\max_j v_{ij} | i \in I' \right), \left(\min_j v_{ij} | i \in I'' \right) \right\}, \quad (7)$$

$$A^- = \{v_1^-, \dots, v_n^-\} = \left\{ \left(\min_j v_{ij} | i \in I' \right), \left(\max_j v_{ij} | i \in I'' \right) \right\}, \quad (8)$$

where I' is associated with benefit criteria, and I'' is associated with cost criteria.

Step 4. The separation measures are calculated using the n-dimensional Euclidean distance. The separation of each alternative from the ideal solution is given as

$$d_j^+ = \sqrt{\sum_{i=1}^n (v_{ij} - v_i^+)^2}, j = 1, \dots, J. \quad (9)$$

Similarly, the separation from the negative-ideal solution is given as

$$d_j^- = \sqrt{\sum_{i=1}^n (v_{ij} - v_i^-)^2}, j = 1, \dots, J. \quad (10)$$

Step 5. The next step consists of the calculation of the relative closeness to the ideal solution. The relative closeness of the alternative a_j with respect to A^+ is defined as

$$D_j = \frac{d_j^-}{(d_j^+ + d_j^-)}, j = 1, \dots, J. \quad (11)$$

Step 6. At the final step, the preference order is ranked.

In TOPSIS method, the chosen alternative has the maximum value of D_j with the intention to minimize the distance from the ideal solution and to maximize the distance from the negative-ideal solution [32].

3. 3. Data Envelopment Analysis (DEA)

Data envelopment analysis (DEA) is a method to calculate relative efficiency of a decision making unit (DMU) by comparing it with linear configurations involved in other DMUs. Decision making units are homogeneous units with the same inputs and outputs. The researchers have focused more often on measuring efficiency due to its importance in assessing the functions of an organization.

In an enterprise by Farrell, an economist, a nonparametric method was provided to determine the relative efficiency [33]. He produced a method for calculating minor levels of efficient production borders from a set of decision maker units observed empirically. The well-known paper of Charnes et al. [34] introduces DEA: a technique based on linear planning to measure some kind of efficiency indicated by Farrell. The model provided by Charles et al. could measure units with several inputs and outputs. This model is one of the basic models in data envelopment analysis and it is known as CCR, in which returns-to-scale is assumed to be fixed.

Banker et al. [35] developed a model assumed to be variable returns-to-scale, known as BCC. In recent decades, applications of DEA have been expanded rapidly (for more information, see [36]). The following Model shows an input oriented CCR model.

$$\text{Min } y_0 = \theta$$

st :

$$\sum_{j=1}^n \lambda_j y_{rj} \geq y_{r0} \quad (r = 1, 2, \dots, s) \quad (12)$$

$$\sum_{j=1}^n \lambda_j x_{ij} \leq \theta x_{i0} \quad (i = 1, 2, \dots, m)$$

$$\lambda_j \geq 0, \quad \theta : \text{Free}$$

Where the value calculated for θ indicates the rate of efficiency for examined DMU by j_0 ; y_{rj} and x_{ij} are r^{th} output and i^{th} input of j^{th} DUM, respectively, y_{r0} and x_{i0} are r^{th} output and i^{th} input of examined DMU, respectively.

In order to assess the efficiency of units, the following is considered to select an appropriate model:

- 1- In this paper, in addition to the inputs and outputs, there are some environmental factors which must be incorporated into the model.
- 2- Since the input oriented and output oriented models provide the same results, then an input oriented model is used.
- 3- In order to select the units being improved, non-decreasing returns-to-scale is considered in the model.

Therefore, in order to measure the efficiency of six sigma projects and considering the environmental factors, we propose an input oriented model with non decreasing returns-to-scale (NDRS) as follows:

$$\text{Min } Z_0 = \theta - \sum_{i=1}^2 \varepsilon_i . Sn_i - \sum_{r=1}^3 \varepsilon_r . Sp_r$$

s.t :

$$\sum_{j=1}^9 y_{rj} \lambda_j - Sp_r = y_{r0} \quad r = 1, \dots, 5.$$

$$\sum_{j=1}^9 x_{ij} \lambda_j + Sn_i - \theta . x_{i0} = 0 \quad i = 1, 2, 3. \quad (13)$$

$$\sum_{j=1}^9 E_{lj} \lambda_j - \theta . E_{l0} \leq 0 \quad l = 1, \dots, 10.$$

$$\sum_{j=1}^9 \lambda_j \geq 1$$

$$\lambda_j, Sp_r, Sn_i \geq 0, \quad \theta : \text{Free}$$

Where variables, homograph with the model (12), have the same definition, and ε_i , Sn_i , and Sp_r are added to it to improve the model. E_{lj} shows l^{th} environmental factors for j^{th} DMU, $j = 1, \dots, 9$.

As noted above, in order to assess the efficiency of units in DEA, the attributes must be categorized into input and output variables. Here, there are some attributes which are neither input, nor output, but they can influence the efficiency of units. These attributes are environmental factors or variables. The input variables are: cost of project (Cost) and duration of executing the project (Time). The output variables are: drop-off in costs due to poor quality (COPQ), customer's satisfaction (Customer), and increasing the sigma level (Sigma). The responsibility of top management (Top Mngr) is considered as an environmental factor or variable.

4. Comparing and determining the importance of criteria for selecting a six sigma project

After determining the criteria, the next step is to define the importance and the priority of them. This step is necessary for used techniques of MCDM (TOPSIS, AHP), but it isn't necessary in DEA. The criteria degree of importance is performed in AHP by pairwise comparison method so that the criteria are compared two by two and the criteria, which is recognized the most important, is given a score from 1 to 9 by decision maker. The score of second criteria is two times more than the reverse score of the first, so it is between 1 and 1/9 (see part 1. 2) the steps for determining the importance of criteria are performed by Expert Choice software. Fig.2 depicts ranking and importance degree of criteria.

Figure 2: Ranking and importance degree of criteria

As you can see, responsibility of top management (Top Mngr) is the most important criteria for selecting project with the score 0.442. The other criteria and their importance are as follows: customer's satisfaction (Customer) 0.276, drop-off in costs due to poor quality (COPQ) 0.139, increasing the sigma level (Sigma) 0.074, cost of project (Cost) 0.041, and finally duration of executing the project (Time) 0.028. So the inconsistency index is 0.06 and since it is less than 0.10, performed pairwise comparisons are approved.

5. A real example

In this example, containing 20 six sigma projects, we show how each of techniques (DEA, TOPSIS, AHP) results in ranking the projects. Table 3 shows 6 variables for projects, called decision matrix. Data are extensions of an example provided by Dinsh Kumar et al. [29], which is a case study of the cycle DMAIC on starter batteries of locomotives in an Asian country.

Table 3. Values of 6 variables for projects

5. 1. AHP approach

According to the method described above, and using the degree importance of criteria calculated by Expert Choice software (fig. 2), we execute the Analytic Hierarchy Process (AHP). It is obvious that the negative criteria (including cost and time of project) become reversed during calculating the scores of projects. For example, the project which has the most cost, is given the least score of the criteria cost. The results from AHP in Table 4 show that the projects 17, 19, 7, 2, and 11 are in the ranks 1 to 5, respectively. The inconsistency index continues to be 0.06, resulted from the criteria pairwise comparisons and the choices have no influence on it. Thus, total inconsistency index of the model is 0.06, since it is lower than 0.1, results of AHP are valid.

Table 4: Scores and ranking the projects by AHP

5. 2. TOPSIS approach

The final weight of choices is calculated by TOPSIS according to the steps in part 2.2.

Step 1: At first, we descale the decision matrix in table 3 by using Euclidian norm according to the expression (5). Table 5 shows the descaled decision matrix.

Table 5. Normalized decision matrix by using Euclidian norm

Step 2: we calculate the weight descaled matrix according to the expression (6), by using the descaled decision matrix and the weight criteria vector (w) obtained by AHP. Table 6 shows the weight descaled matrix.

Table 6. Weighted normalized decision matrix

Table 7. Weight vectors (w), positive Ideal Solution (A^+) and negative Ideal Solution (A^-)

Step 3: The positive and negative Ideal Solutions are calculated by the expressions (7) and (8). Table 7 shows the weight criteria vector (w) and the positive (A^+) and negative (A^-) Ideal Solutions.

Steps 4, 5, and 6: in these steps the distance of each choice is calculated by the positive and negative Ideal Solutions from expressions (9) and (10), then the relative distance of each choice to the ideal solution is determined. The relative distance to the positive ideal solution is calculated by expression (11). The bigger the value of relative distance (D_i) to the positive ideal solution, the choice is more desirable. In the final step, we order the choices according to their values of D_i . Table 8 shows the choice distances to the positive ideal solution (d_i^+), the choice distances to the negative ideal solution (d_i^-), the relative distance to the positive ideal solution (D_i), and ranking resulted from TOPSIS.

Table 8. Choice distances to positive and negative Ideal Solution, and relative choice distances to the ideals (D_i)

The last column of Table 8, shows the ranks of projects determined by TOPSIS, in which the projects 17, 19, 7, 2, and 11 are ranked as 1 to 5, respectively. By comparing the results from AHP and TOPSIS methods, we observe a considerable similarity, whilst there are some minute differences. These differences are observed in projects 5, 8, 13, 15, and 18, which have no sensitive ranks. So these differences have no effect on decision making.

5. 3. DEA approach

The followings are considered in selecting an appropriate DEA in order to assess the efficiency of units:

- 1- In addition to the input and output criteria, there are some environmental criteria incorporated in the model in this paper.
- 2- Since the models of axial input and axial output provide the same results in terms of ranking the units, here the axial input model is used.
- 3- In order to select the units being improved, non-decreasing returns-to-scale (NDRS) is considered in the model.

Therefore, it is used an improved axial input model with non-decreasing returns-to-scale (NDRS), considering the environmental factors (13).

The input attributes are: cost of project (Cost) and duration of executing the project (Time). The output attributes are: drop-off in costs due to poor quality (COPQ), customer's satisfaction (Customer), and increasing the sigma level (Sigma). The only environmental factor is responsibility of top management (Top Mngr).

After primary execution of the model, we observe that 4 projects (7, 12, 17, and 19) are on the efficient frontier and their efficiency is equal to 1. In order to ranking the efficient projects, the methods of ranking efficient units are used and the values of super-efficiency are obtained [38]. The values of super-efficiency for efficient units (which their efficiency is less than 1) are the same values of their efficiency. In input oriented models, the values of super-efficiency for efficient units are higher than 1 and it allows ranking the efficient units. To solve the problems, the DEA Solver software was used. Table 9 shows the values of efficiency and super-efficiency for projects, as well as their ranking.

Table 9: scores and ranks of six sigma projects, using DEA

It is shown that the projects 12, 19, 17, 7, and 2 are in the ranks 1 to 5, respectively.

6. Discussion and conclusion

First step in reducing the risk of failure in six sigma projects is selecting the optimized projects. To achieve this goal, at first the key criteria in selecting the six sigma projects are defined, compared, and ranked. Then, a numerical example including 20 six sigma projects was resolved by using two important techniques in decision making, AHP and TOPSIS. Then the relative efficiency of projects was calculated by dividing the criteria into input and output variables and environmental factors and with the aid of DEA technique. Comparing the ranks from three above techniques indicates the high similarity between the results from AHP and TOPSIS, whilst there are many differences between these results and the results from DEA. To define these differences much more exactly, we calculated the difference squares of ranks of projects for each pair of techniques according expressions (14), (15), and (16). Table 10 shows the results from these expressions.

Table 10. The mean of difference squares of ranks of projects in each pair of techniques

$$M_{AHP, TOPSIS} = \sum_{i=1}^n \frac{(A_i - T_i)^2}{n} \quad (14)$$

$$M_{AHP, DEA} = \sum_{i=1}^n \frac{(A_i - D_i)^2}{n} \quad (15)$$

$$M_{DEA, TOPSIS} = \sum_{i=1}^n \frac{(D_i - T_i)^2}{n} \quad (16)$$

A_i : Rank of i^{th} project, using technique AHP

T_i : Rank of i^{th} project, using technique TOPSIS

D_i : Rank of i^{th} project, using technique DEA

N : Total number of projects under examination (here $n=20$)

By a glance on problem solving process of three discussed techniques, obviously, difference between their results is logical. In fact, elements ranking by AHP performs base on pairwais assessments under decision maker's point of view. TOPSIS is founded on both of decision maker's pairwais assessment, and distance of alternatives from ideal solution. While, decision maker's intervention during DEA process is very little, and units are compared with each other and ranked by linear programming model.

As it is obvious from table 10, AHP and TOPSIS lead to very similar results in the problems and cases which have many levels and few criteria, whilst they vary from results of DEA very much. Since selecting six sigma projects is a multi choice decision making and its criteria have different degree of importance, so specialists and decision makers see high dependence in determining criteria degrees of importance. So, Multiple Criteria Decision Making (MCDM) which includes this step provides a solution more reliable than DEA's. Because, as cited before, the decision maker cannot weight the criteria in DEA, so it is recommended to use this method as a decision making tool for problems with definite framework, regardless the decision maker's views.

As a conclusion, findings of current paper recommend to managers not to use DEA to select six sigma projects, if they want to intervene in decision making process. On the other hand, they have to define the exact and complete criteria in order to apply DEA. Also, based on a practical finding, number of projects should be approximately 3 fold of number of criteria. Although, based on the paper results, managers are recommended to use MCDM techniques, because of current problem's nature.

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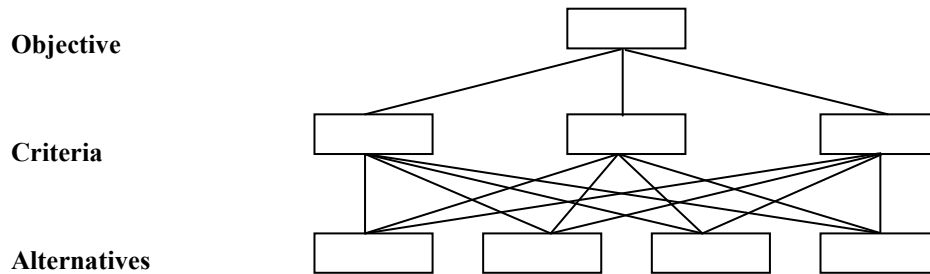


Fig.1. The hierarchical structure of the decision making problem

Table 1. Methods used to select a six sigma project

Author	References	Tools
Pyzdek (2000, 2003)	[22, 23]	Pareto priority index (PPI), AHP, QFD, theory of constraints (TOC)
Breyfogle et al. (2001)	[24]	Project assessment matrix
Pande et al. (2000)	[17]	QFD
Kelly (2002)	[25]	Project selection matrix
Adams et al. (2003)	[26]	Project ranking matrix
Larson (2003)	[27]	Pareto analysis
De Feo and Barnard (2004)	[28]	Reviewing data on potential projects against specific criteria
Dinesh Kumar et al. (2006, 2007)	[3, 29]	AHP, DEA

Table 2. The numerical assessments and their linguistic meanings

Numerical assessment	Linguistic meaning
1	With no importance
3	Less importance
5	Moderately important
7	Strongly important
9	Extremely important
2,4,6,8	Intermediate values of importance

Table 3. Values of 6 variables for projects, called decision matrix

	Cost	COPQ	Time (day)	Costumer	Sigma	Top Mngr
1	212	331	70	11	0.24	0
2	199	342	63	29	0.77	1
3	214	333	88	28	0.33	1
4	280	303	77	29	0.48	0
5	263	240	72	19	0.41	1
6	203	306	70	21	0.52	1
7	196	345	61	31	0.78	1
8	215	264	79	22	0.27	0
9	281	239	71	17	0.66	1
10	233	338	66	10	0.30	1
11	263	310	84	27	0.88	1
12	198	341	60	32	0.51	0
13	220	308	80	15	0.31	1
14	284	325	79	23	0.31	0
15	214	314	87	19	0.54	0
16	235	236	80	27	0.34	1
17	200	339	63	33	0.83	1
18	217	313	75	13	0.74	1
19	198	343	63	31	0.87	1
20	227	317	70	10	0.46	1

Table 4: Scores and ranking the projects by AHP

Project	AHP Scores	AHP Ranking
1	0.019517676	20
2	0.066469291	4
3	0.061947460	6
4	0.031028981	16
5	0.054716421	11
6	0.058762012	8
7	0.067929479	3
8	0.024820670	19
9	0.055120394	10
10	0.050941614	14
11	0.064325556	5
12	0.034995628	15
13	0.053274539	12
14	0.026569908	17
15	0.025878260	18
16	0.059143464	7
17	0.069280998	1
18	0.055280875	9
19	0.068439740	2
20	0.051557034	13

Table 5. Normalized decision matrix by using Euclidian norm

	Cost	COPQ	Time (day)	Costumer	Sigma	Top Mngr
1	0.20657	0.23772	0.21329	0.10422	0.09432	0
2	0.19390	0.24562	0.19196	0.27477	0.30262	0.26726
3	0.20852	0.23916	0.26813	0.26530	0.12970	0.26726
4	0.27283	0.21761	0.23461	0.27477	0.18865	0
5	0.25626	0.17237	0.21938	0.18002	0.16114	0.26726
6	0.19780	0.21977	0.21329	0.19897	0.20437	0.26726
7	0.19098	0.24778	0.18586	0.29372	0.30655	0.26726
8	0.20949	0.18960	0.24071	0.20845	0.10611	0
9	0.27380	0.17165	0.21633	0.16107	0.25939	0.26726
10	0.22703	0.24275	0.20110	0.09475	0.11790	0.26726
11	0.25626	0.22264	0.25594	0.25582	0.34585	0.26726
12	0.19293	0.24490	0.18282	0.30320	0.20044	0
13	0.21436	0.22120	0.24376	0.14212	0.12183	0.26726
14	0.27672	0.23341	0.24071	0.21792	0.12183	0
15	0.20852	0.22551	0.26508	0.18002	0.21223	0
16	0.22898	0.16949	0.24376	0.25582	0.13363	0.26726
17	0.19488	0.24347	0.19196	0.31267	0.32620	0.26726
18	0.21144	0.22479	0.22852	0.12317	0.29083	0.26726
19	0.19293	0.24634	0.19196	0.29372	0.34192	0.26726
20	0.22118	0.22767	0.21329	0.09475	0.18079	0.26726

Table 6. Weighted normalized decision matrix

	Cost	COPQ	Time (day)	Costumer	Sigma	Top Mngr
1	0.00847	0.03304	0.00597	0.02877	0.00698	0
2	0.00795	0.03414	0.00537	0.07584	0.02239	0.11813
3	0.00855	0.03324	0.00751	0.07322	0.00960	0.11813
4	0.01119	0.03025	0.00657	0.07584	0.01396	0
5	0.01051	0.02396	0.00614	0.04969	0.01192	0.11813
6	0.00811	0.03055	0.00597	0.05492	0.01512	0.11813
7	0.00783	0.03444	0.00520	0.08107	0.02268	0.11813
8	0.00859	0.02635	0.00674	0.05753	0.00785	0
9	0.01123	0.02386	0.00606	0.04446	0.01919	0.11813
10	0.00931	0.03374	0.00563	0.02615	0.00872	0.11813
11	0.01051	0.03095	0.00717	0.07061	0.02559	0.11813
12	0.00791	0.03404	0.00512	0.08368	0.01483	0
13	0.00879	0.03075	0.00683	0.03923	0.00902	0.11813
14	0.01135	0.03244	0.00674	0.06015	0.00902	0
15	0.00855	0.03135	0.00742	0.04969	0.01570	0
16	0.00939	0.02356	0.00683	0.07061	0.00989	0.11813
17	0.00799	0.03384	0.00537	0.08630	0.02414	0.11813
18	0.00867	0.03125	0.00640	0.03400	0.02152	0.11813
19	0.00791	0.03424	0.00537	0.08107	0.02530	0.11813
20	0.00907	0.03165	0.00597	0.02615	0.01338	0.11813

Table 7. Weight vectors (w), positive Ideal Solution (A⁺) and negative Ideal Solution (A⁻)

	Cost	COPQ	Time (day)	Costumer	Sigma	Top Mngr
W	0.041	0.139	0.028	0.276	0.074	0.442
A+	0.00783	0.03444	0.00512	0.08630	0.02559	0.11813
A-	0.01135	0.02356	0.00751	0.02615	0.00698	0

Table 8. Choice distances to positive and negative Ideal Solution, and relative choice distances to the ideals (D_i)

	d_i^+	d_i^-	D_i	TOPSIS Ranking
1	0.13272	0.01036	0.07243	20
2	0.01095	0.12957	0.92210	4
3	0.02084	0.12759	0.85957	6
4	0.11929	0.05063	0.29795	16
5	0.04056	0.12056	0.74826	9
6	0.03332	0.12211	0.78561	8
7	0.00599	0.13173	0.95654	3
8	0.12315	0.03165	0.20444	18
9	0.04377	0.12017	0.73300	10
10	0.06249	0.11861	0.65494	14
11	0.01642	0.12780	0.88612	5
12	0.11865	0.05915	0.33269	15
13	0.05008	0.11911	0.70401	11
14	0.12220	0.03521	0.22366	17
15	0.12413	0.02643	0.17554	19
16	0.02483	0.12627	0.83566	7
17	0.00160	0.13412	0.98820	1
18	0.05258	0.11956	0.69456	12
19	0.00525	0.13205	0.96177	2
20	0.06146	0.11861	0.65870	13

Table 9: scores and ranks of six sigma projects, using DEA

	Efficiency	Super Efficiency	DEA Ranking
1	0.93396	0.93396	8
2	0.98507	0.98507	5
3	0.91667	0.91667	10
4	0.77922	0.77922	19
5	0.83333	0.83333	18
6	0.96585	0.96585	7
7	1	1.02725	4
8	0.92093	0.92093	9
9	0.85290	0.85290	15
10	0.90909	0.90909	11
11	0.84825	0.84825	16
12	1	1.56298	1
13	0.89189	0.89189	13
14	0.75949	0.75949	20
15	0.97966	0.97966	6
16	0.83544	0.83544	17
17	1	1.04342	3
18	0.90411	0.90411	12
19	1	1.05878	2
20	0.86649	0.86649	14

Table 10. The mean of difference squares of ranks of projects in each pair of techniques

$M_{AHP, TOPSIS}$	$M_{AHP, DEA}$	$M_{DEA, TOPSIS}$
0.80	47.00	48.60

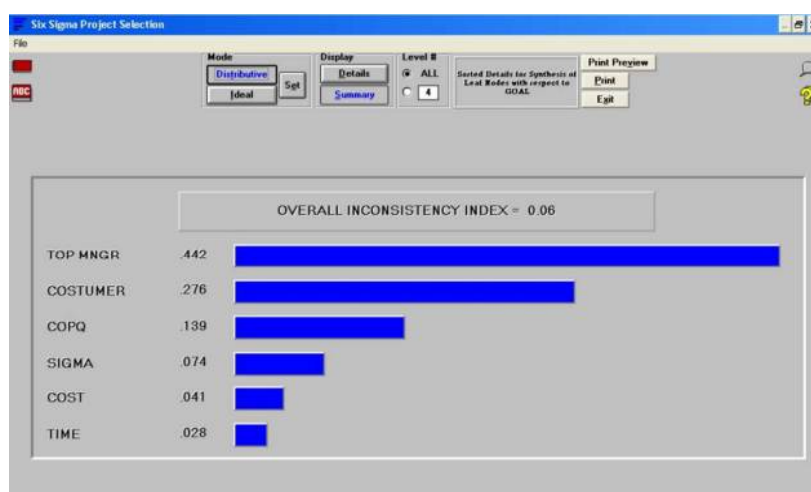


Figure 2: Ranking and importance degree of criteria

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