SIX SIGMA PROJECT SELECTIONS BY USING A FUZZY MULTI CRITERIA DECISION MAKING APPROACH: A CASE STUDY IN POLY ACRYL CORP

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ABSTRACT

Six sigma may be named as a powerful and comprehensive management tool which is necessary in order to bring changes in organization and to make conformity with customer needs. Despite of other quality approaches, six sigma is not only a method, but it contains a vision, a goal and a symbol. Beside the six sigma, symmetrical valuation method is interpreted as a tool to collect strategy. This system offers a method to converge occupation's activities with strategy, and also it offers a method in order to watch the operation of strategic goals during time. Undoubtedly, the first step in reducing the risk failure of the six sigma projects is to select the optimal choices. In this paper, the effectiveness of criteria in choosing six sigma projects are identified and defined. Moreover, a case study in Poly Acryl Corp is illustrated to demonstrate the effectiveness and practicality of the fuzzy multi-criteria decision making approach to select six sigma projects. In fact, we evaluated how selecting six sigma projects and goals using the fuzzy multi-criteria decision making technique affect the organization.

Keywords: Fuzzy Multi-Criteria Decision Making and Decision Analysis, Quality Management

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1 INTRODUCTION

Over the past few years, manufacturing companies have been successful in leveraging six sigma, as a corporate strategy, to reduce the number of defective units from manufacturing processes thereby reducing costs and improving profits. Six sigma is now often thought of as the new mantra in the corporate world. The benefits of six sigma are extensively reported in the literature [1-7]. However, there are noticeable cases where six sigma failed to deliver the desired results. A survey conducted by the Aviation Week magazine among major aerospace companies reported that less than 50 percent of the companies expressed satisfaction with results from six sigma projects, nearly 30 percent were dissatisfied and around 20 percent were somewhat satisfied [8].Of significant note, the study identified that 60 percent of the companies in the survey selected opportunities for improvement on an ad hoc basis, while only 31 percent relied on a portfolio approach. However, the study shows that companies actually achieve better results when applying the portfolio approach. Among all, the process improvement techniques used in the last five decades, six sigma has clearly emerged as the most effective quality improvement technique as pointed out in a survey conducted by DynCorp [9].

In essence, six sigma is an extension of other quality initiatives such as Deming's statistical quality control and total quality management (TQM). Six sigma, as with most of the management strategies on quality initiatives is focused around meeting the customer requirements as its main objective. Six sigma can be defined as a strategy that includes TQM, strong customer focus, additional data analysis tools, financial results and project management [10 and 11]. Although six sigma originated in the manufacturing industry to reduce the wastes due to manufacturing process deficiencies, it is now used by almost all industries including service industries such as health care management [12-15]. Contrary to this wide application potential, none of the other quality improvement initiatives received such high application outside the manufacturing industry [16].

For many companies, the question is not whether or not to implement six sigma, but how to implement a successful six sigma process improvement project. The selection of process improvement projects is probably the most difficult aspect of six sigma [17 and 18]. Bertels pointed out that the key characteristics differentiating successful six sigma projects from unsuccessful projects is a well-defined project based on the clear and concise description of the project objectives [19]. Selecting six sigma projects is one of the most frequently discussed issues in the six sigma literature today [20 and 21].Whenever different six sigma projects are competing for implementation, management is interested in identifying those projects that result in the maximum benefit to the organization. Table 1 provides the list of tools used for six sigma project selection [22]. In this paper, the basis of fuzzy TOPSIS method is described, then this approach is used to rank the project which is selected in six sigma committee in Poly Acryl corp.

Table 1: Methods Used For Selecting Of Six Sigma Projects

Author	Tool(s)
Pyzdek [23,24]	Pareto priority index (PPI), AHP, QFD, theory of constraints (TOC)
Breyfogle *et al.* [25]	Project assessment matrix
Pande *et al.* [26]	QFD
Kelly [27]	Project selection matrix
Adams *et al.* [28]	Project ranking matrix
Larson [29]	Pareto analysis
De Feo and Barnard [30]	Reviewing data on potential projects against specific criteria
Kumar *et al.* [31,32]	AHP

2 METHODOLOGY

Fuzzy multi-criteria decision making TOPSIS method, which is based on choosing the best option with the least distance from the positive ideal solution and the greatest distance from the negative ideal, was proposed by Hwang and Chen in 1981 [5]. The positive ideal maximizes the advantages and minimizes the total cost and negative ideal minimize the advantages and maximize the cost. Also they presented the fuzzy multi-criteria decision making methods in 1992 [33]. FTOPSIS method involves the following steps.

Step 1: Formation Of The Decision Matrix

According to the criteria, the number of options and assess all options for the different criteria, decision matrix is formed as presented in equation (1).

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \tilde{x}_{ij} & \vdots \\ \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix} \quad (1)$$

A triangular fuzzy number, $x_{ij}= (a_{ij},b_{ij},c_{ij})$, is the performance of option i (i = 1,2, ..., m) in relation to criteria j (j = 1,2, ..., n). If the number of decision makers is k and k^{th} fuzzy ranking decision maker is shown by $x_{ijk}= (a_{ijk}, b_{ijk}, c_{ijk})$, the combination of fuzzy ranking criteria $x_{ij} = (a_{ij}, b_{ij}, c_{ij})$ can be obtained from formulation presented in equation set (2).

$$a_{ij} = min_k \{a_{ijk}\}, \; b_{ij} = \frac{\sum_{k=1}^{k} b_{ijk}}{k}, \; c_{ij} = max_k \{c_{ijk}\} \quad (2)$$

Step 2: Determining The Weights Of Criteria

The coefficient of criteria, is defined as W = $[w_1,w_2,…,w_n]$. If the triangular fuzzy numbers are used, each of the components w_j is defined as $w_j = (w_{j1}, w_{j2}, w_{j3})$. If the number of decision makers is k, the k^{th} weight is $w_{jk} = (w_{jk1}, w_{jk2}, w_{jk3})$ for j = 1,2, ..., n and the fuzzy ranking $w_j = (w_{j1}, w_{j2}, w_{j3})$ can be obtained through the equation set (3).

$$w_{j1} = min_k \{w_{jk1}\}, \; w_{j2} = \frac{\sum_{k=1}^{k} w_{ij2}}{k}, \; w_{j3} = max_k \{w_{jk3}\} \quad (3)$$

Step3: Removing The Scales

If one uses fuzzy numbers for x_{ij}, then he should use fuzzy numbers for r_{ij}, too. Instead of the complex calculations of the classical model, the linear scale transformation used in different criteria in order to normalize them. Using triangular fuzzy numbers, the decision matrix for the positive and negative aspect is calculated through the equations (4) to (7).

$$\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right) \quad (4)$$

$$\tilde{r}_{ij} = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right) \quad (5)$$

$$c_j^* = max_i \, c_{ij} \quad (6)$$

$$a_j^- = min_i \, a_{ij} \quad (7)$$

The fuzzy decision matrix (r) without scale is obtained via equations (8) and (9), in which m represents the number of options and n represents the number of criteria.

$$\tilde{R} = [\tilde{r}_{ij}]_{m*n} \quad (8)$$

$$\tilde{R} = \begin{bmatrix} \tilde{r}_{11} & \cdots & \tilde{r}_{1n} \\ \vdots & \tilde{r}_{ij} & \vdots \\ \tilde{r}_{m1} & \cdots & \tilde{r}_{mn} \end{bmatrix} \quad (9)$$

Step 4: Determining The Weighted Fuzzy Decision Matrix

By considering the weight of different criteria, the weighted fuzzy decision matrix is obtained through $\tilde{v}_{ij} = \tilde{r}_{ij}.\tilde{w}_j$, in which, $\tilde{w}_j$ represents the importance of c_j. Thus, the fuzzy decision matrix can be presented as equation (10).

$$\tilde{v} = \begin{bmatrix} \tilde{v}_{11} & \cdots & \tilde{v}_{1n} \\ \vdots & \tilde{v}_{ij} & \vdots \\ \tilde{v}_{m1} & \cdots & \tilde{v}_{mn} \end{bmatrix} \quad \textbf{(10)}$$

Using the triangular fuzzy numbers, the positive and negative aspects can be calculated in equations (11) and (12).

$$\tilde{v}_{ij} = \tilde{r}_{ij}.\tilde{w}_j = \left(\frac{a_{ij}}{c_j^*}, \frac{b_{ij}}{c_j^*}, \frac{c_{ij}}{c_j^*}\right).(w_{j1}, w_{j2}, w_{j3}) = \left(\frac{a_{ij}}{c_j^*}.w_{j1}, \frac{b_{ij}}{c_j^*}.w_{j2}, \frac{c_{ij}}{c_j^*}w_{j3}\right) \quad \textbf{(11)}$$

$$\tilde{v}_{ij}^- = \tilde{r}_{ij}.\tilde{w}_j = \left(\frac{a_j^-}{c_{ij}}, \frac{a_j^-}{b_{ij}}, \frac{a_j^-}{a_{ij}}\right).(w_{j1}, w_{j2}, w_{j3}) = \left(\frac{a_j^-}{c_{ij}}.w_{j1}, \frac{a_j^-}{b_{ij}}.w_{j2}, \frac{a_j^-}{a_{ij}}w_{j3}\right) \quad \textbf{(12)}$$

Step 5: Finding the fuzzy ideal solution and fuzzy anti-ideal solution

The fuzzy ideal solution can be defined as $A^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \dots, \tilde{v}_n^*\}$ and fuzzy anti-ideal solution is presented as $A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \dots, \tilde{v}_n^-\}$; *where,* $\tilde{v}_i^*$ is the best value among all the criteria and $\tilde{v}_i^-$ is the worst option. These values are obtained through equations (13) and (14). The options appeared in A^* and A^{-}, indicate the best and the worst solutions, respectively.

$$\tilde{v}_i^* = max_i\{v_{ij3}\},\ i = 1,2,\dots,m,\ j = 1,2,\dots,n \quad \textbf{(13)}$$

$$\tilde{v}_i^- = min_i\{v_{ij1}\},\ i = 1,2,\dots,m,\ j = 1,2,\dots,n \quad \textbf{(14)}$$

Step 6: Calculating the distance from the fuzzy ideal and fuzzy anti-ideal solutions

The distance from the fuzzy ideal and anti-ideal solutions, for option I is calculated through equations (15) and (16). Moreover, the distance between two fuzzy numbers (a1,b1,c1) and (a2,b2,c2) can be calculated through equation (17).

$$S_i^* = \sum d(v_{ij}, v_j^*),\ i = 1,2,\dots,m \quad \textbf{(15)}$$

$$S_i^- = \sum d(v_{ij}, v_j^-),\ i = 1,2,\dots,m \quad \textbf{(16)}$$

$$d(M1, M2) = \sqrt{\frac{1}{3}}[(a_1 - a_2)^2 + (b_1 - b_2)^2 + (c_1 - c_2)^2] \quad \textbf{(17)}$$

Step 7: Calculate the similarity index

Similarity index is calculated through equation (18).

$$CC_j = \frac{S_i^-}{S_i^- + S_i^*} \quad \textbf{(18)}$$

Step 8: Ranking the options

At this stage, according to similarity index, the options are ranked so that the similarity index options with higher priority ranked in higher position.

Selecting Criteria To Evaluate The Six Sigma Projects

The impact to the corporate bottom-line ultimately measures the success of six sigma projects. Selection of an appropriate six sigma project requires careful analysis. The chosen project should align with the strategic objectives of the organization. Pande *et al.* [17] classified six sigma project selection criteria into three categories: business benefits criteria; feasibility criteria and organization impact criteria. Business benefits criteria include issues such as the impact on customers, the impact on business strategy, and the impact on core competencies, financial impact and urgency. Feasibility criteria for six sigma project selection include criteria such as resources needed, expertise available, complexity, and probability of success. Learning benefits and cross-functional benefits are listed under organizational impact criteria.

Harry and Schroeder propose some criteria for six sigma project selection. Their criteria include defects per million opportunities (DPMO), net cost savings; COPQ, cycle time, customer satisfaction, capacity, and internal performance [19]. Furthermore, Banuelas *et al.* [22] list the following six critical criteria to select six sigma project, including, customer impact, financial impact, top management commitment, measurable and feasible, learning and growth, and connected to business strategy and core competence.

3 SELECTING A SIX SIGMA PROJECT IN POLY ACRYL IRAN CORP.

Poly Acryl Iran has used Six Sigma methodology to reduce the cost since 2005. In this paper, in accordance to the opinions of three corporate managers five criteria are proposed to evaluate and prioritize three six sigma projects submitted to the steering committee of six sigma. The evaluation criteria are defined as:

1. Project cost reduction
2. Reduce the cost of poor quality
3. Reduce the period of project implementation
4. Increasing Customer Satisfaction
5. Increasing Sigma level

Step 1: Evaluation Of The Importance Of Criteria

Five linguistic variables were used to assess the importance of each criterion. These linguistic variables and their respective fuzzy number are presented in table 2. The managers were asked to evaluate the importance of each criterion in terms of the linguistic variables which is presented in table 3. Moreover, they defined fuzzy numbers for each criterion, which is presented in table 4.

Table 2: Definition Of The Variables For The Criteria

Variable	Importance	Fuzzy Number
VL	Very Low	(0,0,0.2)
L	Low	(0.1,0.2,0.3)
M	Medium	(0.4,0.5,0.6)
H	High	(0.7,0.8,0.9)
VH	Very High	(0.8,1,1)

Table 3: The Importance Of Various Criteria Based On Managers' Opinion

Criteria	Manager1	Manager2	Manager3
C1	M	H	VH
C2	H	H	VH
C3	L	M	VL
C4	H	VH	H
C5	M	VH	H

Table 4: Fuzzy Numbers Of The Criteria According To The Managers' Opinion

Criteria	Manager1	Manager2	Manager3
C1	(0.4,0.5,0.6)	(0.7,0.8,0.9)	(0.8,1,1)
C2	(0.7,0.8,0.9)	(0.7,0.8,0.9)	(0.8,1,1)
C3	(0.1,0.2,0.3)	(0.4,0.5,0.6)	(0,0,0.2)
C4	(0.7,0.8,0.9)	(0.8,1,1)	(0.7,0.8,0.9)
C5	(0.4,0.5,0.6)	(0.8,1,1)	(0.7,0.8,0.9)

Step 2: Ranking Of The Project Options

Five linguistic variables are defined to rank the project options in accordance to the aforementioned criteria. These variables and their fuzzy numbers are presented in table 5. Then, each manager was asked to evaluate the rank of the project options according to each criterion, which is reported in table 6. The managers' opinion for each project option and the criteria are expressed in fuzzy numbers and presented in table 7.

Table 5: Definition Of The Variables To Evaluate Criteria In Each Project Option

Variable	Importance	Fuzzy Number
VU	Very unsuitable VU	(1,1,3)
U	unsuitable U	(1,3,5)
F	Fairly suitable F	(3,5,7)
S	Suitable S	(5,7,9)
VS	Very suitable VS	(7,9,9)

Table 6: Importance Of Three Projects According To Managers' Opinion

Option	C1			C2			C3			C4			C5		
	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3	M1	M2	M3
P1	S	S	VS	U	F	VU	S	F	VS	VS	F	F	S	S	VS
P2	F	VS	F	S	S	F	S	S	F	F	VS	S	VS	F	S
P3	VS	S	F	VS	F	S	F	VS	S	S	VS	F	S	F	VS

Table 7: Fuzzy Numbers For The Criteria In Three Projects Based On Managers' Opinion

Criteria	Option	M1	M2	M3
	P1	(5,7,9)	(5,7,9)	(7,9,9)
C1	P2	(3,5,7)	(7,9,9)	(3,5,7)
	P3	(7,9,9)	(5,7,9)	(3,5,7)
	P1	(1,3,5)	(3,5,7)	(1,1,3)
C2	P2	(5,7,9)	(5,7,9)	(3,5,7)
	P3	(7,9,9)	(3,5,7)	(5,7,9)
	P1	(5,7,9)	(3,5,7)	(7,9,9)
C3	P2	(5,7,9)	(5,7,9)	(3,5,7)
	P3	(3,5,7)	(7,9,9)	(5,7,9)
	P1	(7,9,9)	(3,5,7)	(3,5,7)
C4	P2	(3,5,7)	(7,9,9)	(5,7,9)
	P3	(5,7,9)	(7,9,9)	(3,5,7)
	P1	(5,7,9)	(5,7,9)	(7,9,9)
C5	P2	(7,9,9)	(3,5,7)	(5,7,9)
	P3	(5,7,9)	(3,5,7)	(7,9,9)

Steps 3&4: Determining The Weight Of Criteria, And Its Normalization

In this step, based on the data reported in table 7, the fuzzy decision matrix and fuzzy weights of the criteria are calculated and illustrated in table 8. In next step, the fuzzy weights are normalized and the results are reported in table 9.

Table 8: Fuzzy Decision Matrix Based On The Managers' Opinion

	C1	C2	C3	C4	C5
weight	(0.4,0.76,1)	(0.7,0.86,1)	(0,0.23,0.6)	(0.7,0.86,1)	(0.4,0.76,1)
P1	(5,7.6,9)	(1,3,7)	(3,7,9)	(3,6.3,9)	(5,7.6,9)
P2	(3,6.3,9)	(3,6.3,9)	(3,6.3,9)	(3,7,9)	(3,7,9)
P3	(3,7,9)	(3,7,9)	(3,7,9)	(3,7,9)	(3,7,9)

Table 9: Normalized Fuzzy Weight For The Criteria

	C1	C2	C3	C4	C5
P1	(0.55,0.84,1)	(0.11,0.33,0.77)	(0.33,0.77,1)	(0.33,0.77,1)	(0.55,0.84,1)
P2	(0.33,0.7,1)	(0.33,0.7,1)	(0.33,0.7,1)	(0.33,0.7,1)	(0.33,0.7,1)
P3	(0.33,0.77,1)	(0.33,0.77,1)	(0.33,0.77,1)	(0.33,0.77,1)	(0.33,0.77,1)

Steps 5&6: Determining The Weighted Fuzzy Decision Matrix, And Fuzzy Solution

The weighted fuzzy decision matrix for each project option is illustrated in table 10.Then, the fuzzy ideal solution, and the fuzzy anti-ideal solution can be calculated which are shown as P^* and P^-, respectively.

Table 10: Normalized Fuzzy Weight For The Criteria

	C1	C2	C3	C4	C5
P1	(0.22,0.63,1)	(0.07,0.28,0.77)	(0,0.17,0.6)	(0.23,0.6,1)	(0.22,0.63,1)
P2	(0.13,0.53,1)	(0.23,0.6,1)	(0,0.16,0.6)	(0.23,0.66,1)	(0.13,0.58,1)
P3	(0.13,0.58,1)	(0.23,0.66,1)	(0,0.17,0.6)	(0.23,0.66,1)	(0.13,0.58,1)

$$P^* = \{(1,1,1), (1,1,1), (0.6,0.6,0.6), (1,1,1), (1,1,1)\}$$

$$P^- = \{(0.13,0.13,0.13), (0.07,0.07,0.07), (0,0,0), (0.23,0.23,0.23), (0.13,0.13,0.13)\}$$

Steps 7&8: Calculating The Distance And Ranking The Projects

In step 7, the distance of each criterion from its ideal and anti-ideal value is calculated and presented in tables 11 and 12. Then, distance of the projects from the ideal and anti-ideal solutions is reported in table 13. Moreover, the similarity index is shown for each project option. Finally, in the 8^{th} step, according to the similarity index, the project options are ranked, which can be expressed as P3, P2 and P1.

Table 11: Distance Of The Criteria From Their Ideal Values In Each Project Option

	C1	C2	C3	C4	C5	sum
P1	0.498	0.692	0.426	0.501	0.498	2.616
P2	0.571	0.501	0.430	0.486	0.558	2.545
P3	0.558	0.486	0.426	0.486	0.558	2.514

Table 12: Distance Of The Criteria From Their Anti-Ideal Values In Each Project Option

	C1	C2	C3	C4	C5	sum
P1	0.582	0.422	0.360	0.493	0.582	2.439
P2	0.553	0.625	0.359	0.509	0.566	2.611
P3	0.566	0.643	0.360	0.509	0.566	2.643

Table 13: Distance Of The Project Options From The Ideal And Anti-Ideal Solutions

	P1	P2	P3
distance from the fuzzy ideal solution	2.616	2.545	2.514
distance from the fuzzy anti-ideal solution	2.439	2.611	2.643
Similarity index	0.482	0.506	0.512

4 CONCLUSIONS

The first step in reducing the risk failure of the six sigma projects is to select optimal projects, the Projects that gain the maximum benefit and minimum risk are expected.

Therefore in this paper the criteria in choosing Six Sigma projects were identified and ranked. After determining the degree and importance (weight) of criteria, a project was selected by using FTOPSIS in Poly Acryl corp. and the P3 was selected. The use of the proposed model can help company facilitating the decision-making and using a systematic approach to select the appropriate projects. It is recommended that resolve other problems like supplier selection or etc. by this methodology.

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