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Six Sigma Project Selection Using Fuzzy TOPSIS Decision Making Approach

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A B S T R A C T

Six Sigma is considered as a logical business strategy that attempts to identify and eliminate the defects or failures for improving the quality of product and processes. A decision on project selection in Six Sigma is always very critical; it plays a key role in successful implementation of Six Sigma. Selection of a right Six Sigma project is essentially important for an automotive company because it greatly influences the manufacturing costs. This paper discusses an approach for right Six Sigma project selection at an automotive industry using fuzzy logic based TOPSIS method. The fuzzy TOPSIS is a well recognized tool to undertake the fuzziness of the data involved in choosing the right preferences. In this context, evaluation criteria have been designed for selection of best alternative. The weights of evaluation criteria are calculated by using the MDL (modified digital logic) method and final ranking is calculated through priority index obtained by using fuzzy TOPSIS method. In the selected case study, this approach has rightly helped to identify the right project for implementing Six Sigma for achieving improvement in productivity.

1. Introduction

Six Sigma is a highly commanding improvement strategy that is applied in organizations to drive and endlessly sustain transformational raise in the organization. It is a structured and organized technique for process enhancement, innovative creation and service development that is based on the scientific and statistical methods to make remarkable reduction in defect rates (Linderman et al., 2003). It has been recognised as a dominant business strategy that utilizes a well controlled unremitting improvement methodology to lessen process variability and force out capacity waste inside the processes using quality management and statistical techniques(Banuelas, Antony, & Brace, 2005). It is a well-organized process that focuses on producing and conveying products and services in a stable manner. It makes use of statistical tools and project management techniques to attain improvements in process and quality. Its role is in getting better improvement and manufacturing actions has been well recognized. But not a lot of people realize that it has been making a great impact on a broad variety of new tasks and methods. This also includes transactional activities such as designing measures to

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improve processes and reduce cycle time in business planning, sales, services, production processes and human resources etc. (Yun & Chua, 2002). It is an industrial strategy, which can satisfy the general interests of each element in the corresponding chain, including customers, suppliers, personnel and business leaders. It can raise the level of process and service quality in the corporations and also increase the overall profit and breakthroughs in business development (Thawani, 2004).

Six Sigma was introduced by Motorola on the manufacturing floor in 1980s. At that period Motorola found that they were losing a huge segment of their business and efficiency through the cost of poor quality. They defined Six Sigma as a quality improvement technique with a purpose of reducing the number of defects to 3.4 parts per million opportunities. It was a move to modernize the capacity and use of quality structure in business arena. (Chakrabarty & Chuan Tan, 2007). It is a statistically based process escalation strategy that focuses to decrease defects by recognizing and removing causes of deviation in processes. Six Sigma strategies provide the tools and techniques to develop the capability and lessen the defects in any business process (Goh, 2002). The name Six Sigma has originated from the Greek letter sigma (**σ**). The Greek alphabet is used to represent standard deviation in statistics and to measure the variability in any process (Pyzdek, 1999). The performance of any company is measured by their corresponding sigma level. In statistics Six Sigma is defined as six standard deviations from mean, which in a parametric manner would include 99.99% of the yield (Pyzdek & Keller, 2003). When Six Sigma was initiated in 1980s and 1990s, it was just a quality improvement technique and works on continuous improvement strategy. But this technique was not so successful because it did not have directional support. In next generation of Six Sigma in late 1990s; a new step was added by General Electric to Six Sigma strategy named as “Define” to identify and prioritize problems in a proper directional manner. This addition completes the DMAIC improvement methodology now widely used to execute Six Sigma projects. Define phase is the crucial step in selecting the optimal project by emphasizing on the customer requirements. (Antony, 2006; Bertels, 2003; Sonphuak & Rojanarowan, 2013).

The most complicated task of Six Sigma is the selection of improvement projects probably. The question for most of the business is how to implement a flourishing Six Sigma project (Banuelas Coronado & Antony, 2002). Six Sigma projects selection is one of the most commonly argued issue in the literature these days because most of the improvement projects get failed due to improper selection (Fundin & Cronemyr, 2003). Six Sigma success or failure in any business based on selecting the right project that can be concluded within a targeted time period and that will provide business profit in economic way and improve customer satisfaction. Changes can possible through right project selection in Six Sigma business and right selection of project is very critical issue in the success of business(Jackenthal, 2004). In any Six Sigma project, project selection cited as critical activity and also usually taken up very lightly in initializing Six Sigma. Project selection describes how companies set their priorities for successful implementation of Six Sigma (Dinesh et al., 2007). Most of the companies did not have any project selection technique that helps in timely finishing of the project. Right project selection plays a major role in the early success and long term acceptance of Six Sigma within any business. Right project selection depends on recognizing the projects that manage the business ability and goal (Kumar et al., 2009). Most of the projects fails or drop behind plan due to a weak connection of these projects to the tactical business targets(Banuelas Coronado & Antony, 2002). A proper project selection is a very essential activity for success of Six Sigma strategy due to the fact that wrong project selection can seriously influence the total effectiveness and productivity of a business. Working on a correct project can improve the manufacturing systems, provide efficient capacity utilization, and improve flexibility. For successful Six Sigma implementation, the importance of right project selection cannot be ignored (Dağdeviren, 2008).

In this study we mainly emphasize on Selection of the right Six Sigma project, which is always the most crucial tasks in the successful execution of Six Sigma in any business(Büyüközkan & Öztürkcan, 2010). In the current problem there are no clear boundaries in views of decision makers (champions, production manager, technical and financial experts etc.) in the brainstorming session while selecting

Six Sigma project. So it essential to estimate the optimal solution in terms of selecting right project using a decision making technique. In this context, Fuzzy TOPSIS decision making is used to select right six sigma projects that result in the highest gain to the business. Fuzzy TOPSIS is a combined application, that makes use of fuzzy set theory and multi attribute decision making (MADM) to attain maximum profit(Yong, 2006). MADM approach is used to select best alternative from the huge amount of alternatives for a set of selection criterion. This approach has been productively used in large variety of decision making problems in engineering research and analysis(Gwo-Hshiung, 2010). It includes VlseKriterijumska Optimisacija I Kompromisno Resenje (VIKOR)(Vats & Vaish, 2013) technique for order preference by similarity to ideal solution (TOPSIS)(Lai, Liu, & Hwang, 1994), analytic hierarchy process (AHP)(Saaty, 2008), weighted product method (WPM)(Zavadskas et al., 2012), simple additive weighting (SAW) (Chou et al., 2008), and many others approaches(Gwo-Hshiung, 2010) and among these, TOPSIS is comes out to be excellent approach of decision making. There is broad range of applications for the TOPSIS method in the field of research studies includes design engineering, manufacturing engineering ,supply chain, business management, health, energy management, environmental science, water resources management, safety and many more (Behzadian et al., 2012; Bottani & Rizzi, 2006; Lo et al., 2010; Yazdani, 2014). The objective of present study is to select right Six Sigma project for improvement under fuzzy environment using fuzzy TOPSIS methodology using MDL weights.

2. Evaluation Criteria for Selection of right Six Sigma Project

For selection of the appropriate Six Sigma project at selected automotive industry in India, seven essential parameters have been recognized. The essential identified parameters are taken out from the literature and from the views of various Six Sigma champions, technical experts, machine operators inside industry and based upon the requirements and expectations of the system where the ultimate project will be executed (Ayağ & Özdemir, 2011; Nguyen et al., 2014). The identified parameters are classified in two groups involving the main parameters and sub parameters.

S.no	Parameters	Code	Sub-Parameters
1	Down Time Cost	C_1	Cost of Losses, Cost of Breakdowns
2	Repair Time	C_2	Mean Recover Time, Preparation time
3	Reliability	C_3	Down Time, Failure rate, Serviceability
4	Rejection	C_4	In process Rejection, Final Rejections
5	Productivity	C_5	Productive Forces
6	Working Environment	C_6	Hazard modes, Comfort, Working space
7	Safety	C_7	Safety Accessories, Safety training

3. Methods

3.1 Modified Digital Logic

MDL is a technique used to determine the weights for the evaluation criteria (Vats & Vaish, 2013). It is a modified version of Digital logic (DL) method. MDL has certain striking advantages over DL method. The foremost of which is that least important criterion is not given zero (0) and two equal important criteria can have an equal numeric value (Dehghan-Manshadi, et al., 2007). It is expected that the parameters listed in the previous section have different impact on the performance of the machine and hence cannot be assigned equal weights. Thus, it becomes important to find out the priorities of each criterion. Based on the experts opinion a decision matrix is formed for a pair-wise comparison. Experts assign 1, 2 and 3 for less, equal or more important parameters respectively. Prior to formation of MDL table, it is must to estimate the number of possible positive decisions as $N= n(n-1)/n$, where n is number of parameters (Vats & Vaish, 2014). Further summation of all positive decisions (D) for a particular parameter on normalization leads to final weight (W_j) as:

$$W_j = \frac{D_j}{\sum_{j=1}^{n} D_j} \tag{1}$$

3.2 Fuzzy Logic

The theory of fuzzy logic was introduced by Zadeh to make conclusions from unclear, indefinite and inexact information. Main objective of fuzzy logic is to provide a calculative structure for knowledge expression and conclusion in a situation of vagueness (Zedeh, 1989).This concept was developed to execute those problems which don't have any clear boundaries between their causes. Fuzzy logic has intermediate or variety of degrees of membership. The coding of the level of membership to every element in the set is described as the membership function of set. Such a set is categorized by a membership function which allocates to every object a rank of membership between 0, 1 (Zadeh, 1965). Fuzzy logic is a dominant tool for modeling indecisive problems in industry and decision making in the lack of exact and whole information. Fuzzy logic approach has verified to be a successful means to derive decision making problems where the available information is indefinite(Zimmermann, 2001). A theory which performs main role in fuzzy logic applications is linguistic variable. Fuzzy logic is a well organized approach that calculates approximately a function through linguistic variables (Zadeh, 1994). As name suggest, linguistic variable is a variable whose values are in words (linguistic terms) in a natural language rather than numbers. Linguistic variable gives a means of approximate description of happening which are very complex to be explanation in conventional terms (Ertuğrul & Karakaşoğlu, 2008). In fuzzy logic conversion scales are used to convert the linguistic values into fuzzy numbers. Linguistic variables have been naturally easy to use in expressing the subjectiveness of decision maker consideration (Zadeh, 1975). Fuzzy approach was used for multiple criteria decision making where the focus is on possibility rather than probability. Different fuzzy numbers are used based on their conditions. In present study we have used trapezoidal fuzzy numbers (b_1, b_2, b_3, b_4) for { $b_1, b_2, b_3, b_4 \in$ R; $b_1 \le b_2 \le b_3 \le b_4$ }as in fig.1. Because of its ease for information processing in a fuzzy culture; the membership function $\mu_b(x)$ of trapezoidal fuzzy number is defined as

$$\mu_b(x) = \begin{cases} \frac{x - b_1}{b_2 - b_1}, & x \in [b_1, b_2] \\ 1, & x \in [b_2, b_3] \\ \frac{b_4 - x}{b_4 - b_3}, & x \in [b_3, b_4] \\ 0, & \text{otherwise} \end{cases} \tag{2}$$

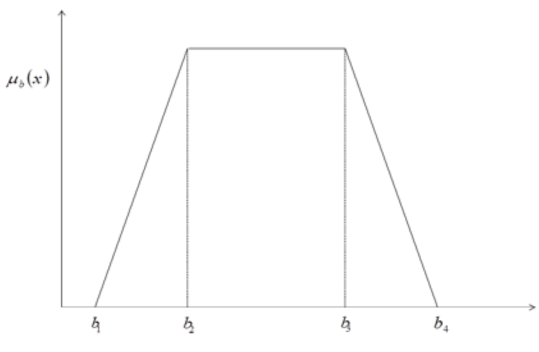

Fig. 1. Trapezoidal fuzzy number

3.3 TOPSIS

Technique for order preference by similarity to an ideal solution (TOPSIS), is well known standard MADM approach, was originally evolved by Hwang and Yoon (Lai et al., 1994). It is a perfect logic based computation method that can be simply executed, which represents sensible human preferences and provides a value that all together accounts for the most excellent and poor alternatives (Kim, Chung, Jun, & Kim, 2013). In TOPSIS the selected alternative should have the shortest distance from the positive ideal solution, and also have the longest distance from the negative ideal solution, to resolve the MADM problems (Yong, 2006).The positive ideal solution enhance the profit criteria and lowers down the cost criteria, where the negative ideal solution enhance the cost criteria and lowers the profit criteria (Wang & Elhag, 2006).TOPSIS assumes that we have ‘s’ number of alternatives and ‘c’ number of selection criteria and we have the rank of each alternative with respect to each criterion.There is a lot of applications based on TOPSIS method reported in literature on project selection (Amiri, 2010; Kim et al., 2013; Mahmoodzadeh et al., 2007).

4. Fuzzy TOPSIS Methodology

This section explains the steps involved in the subjective fuzzy TOPSIS approach for right Six Sigma project selection in an automotive industry. The approach utilizes MDL weights for pair wise comparison among all considered criteria followed by fuzzy logic approach with TOPSIS method to obtain optimal alternatives. It includes following steps:

Step 1: calculation of MDL weights.

As discussed in section 3.1, MDL weights (W_j) are calculated for all project selection parameters. This gives the weights of different criteria.

Step 2: Describe linguistic variables, appropriate membership function and equivalent fuzzy numbers. A set of fuzzy rates is required in order to compare all the alternatives for each criterion. These fuzzy terms are assigned by the decision makers and responsible for intra criterion comparisons of the alternatives.

Step 3: construction of decision matrix.

Let p be the parameters and q be the alternatives. For k number of decision makers in the projected model for the aggregated fuzzy rating for C_j criterion is represented as $x_{ijk} = \{x_{ijk1}, x_{ijk2}, x_{ijk3}, x_{ijk4}\}$.For i =1, 2, .p; j =1, 2….q; k =1, 2….k, x_{ijk} is calculated as(Shemshadi et al., 2011)

$$\begin{cases} x_{ij1} = \min_k \{b_{ijk1}\} \\ x_{ij2} = \frac{1}{k}\sum b_{ijk2} \\ x_{ij3} = \frac{1}{k}\sum b_{ijk3} \\ x_{ij4} = \max_k \{b_{ijk4}\} \end{cases} \tag{3}$$

Thus the obtained decision matrix (M) is shown as:

$$M = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1p} \\ x_{21} & x_{22} & \cdots & x_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ \vdots & \vdots & \ddots & \vdots \\ x_{q1} & x_{q2} & \cdots & x_{qp} \end{bmatrix}$$

Step 4: Defuzzification.

Defuzzification is a method of converting fuzzy output to crisp value (quantified result) in fuzzy logic by real valued functions. It is performed to obtain the crisp values for each criterion corresponding to each alternative. The input for the procedure is the cumulative set and the output is a single number. This provides a quantitative value for the linguistic variables and fuzzy numbers assigned based on the verbal reasoning of the decision makers. Following equation lead to the crisp values:

$$f_{ij} = \text{Defuzz}(x_{ij}) = \frac{\int \mu(x).xdx}{\int \mu(x).dx} = \frac{\int_{x_{ij1}}^{x_{ij2}} \{(x - x_{ij1})/(x_{ij2} - x_{ij1})\}.xdx + \int_{xij2}^{x_{ij3}} xdx + \int_{x_{ij3}}^{x_{ij4}} \{(x_{ij4} - x)/(x_{ij4} - x_{ij3})\}.xdx}{\int_{x_{ij1}}^{x_{ij2}} \{(x - x_{ij1})/(x_{ij2} - x_{ij1})\} dx + \int_{xij2}^{x_{ij3}} dx + \int_{x_{ij3}}^{x_{ij4}} \{(x_{ij4} - x)/(x_{ij4} - x_{ij3})\}.xdx} \tag{4}$$

$$= \frac{-x_{ij1}x_{ij2} + x_{ij3}x_{ij4} + (1/3)(x_{ij4} - x_{ij3})^2 + (1/3)(x_{ij2} - x_{ij1})^2}{-x_{ij1} - x_{ij2} - x_{ij3} + x_{ij4}}$$

The crisp values, thus obtained are integrated with MDL weights to calculate final ranking using TOPSIS approach as discussed below.

TOPSIS Approach Steps

Step 5: Normalized the matrix as given below:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{i=1}^{m} (f_{ij})^2}} ; \forall_j \tag{5}$$

Step 6: Calculate the weighted normalized decision matrix as given:

$$V_{ij} = [r_{ij}]_{m \times n} \times [W_j]_{n \times m}^{diagonal} \tag{6}$$

Step 7: Calculate the positive ideal and negative ideal solution:

The positive ideal solution V_j^+ and negative ideal solution V_j^- are as given below:

$$V_j^+ = \{(\max V_{ij}, j \in J_1), (\min V_{ij}, j \in J_2), i = 1,2,3.....m\}; \forall j \tag{7}$$

$$V_j^- = \{(\min V_{ij}, j \in J_1), (\max V_{ij}, j \in J_2), i = 1,2,3.....m\}; \forall j \tag{8}$$

where J_1 and J_2 represents higher best and lower best criteria respectively.

Step 8: Calculate the distance d_i^+ and d_i^- from the positive ideal solution and negative ideal solution respectively

$$d_i^+ = \left[\sum_{j=1}^{n} (V_{ij} - V_j^+)^2 \right]^{0.5}, i = 1,2,3,.....m \tag{9}$$

$$d_i^- = \left[\sum_{j=1}^{n} (V_{ij} - V_j^-)^2 \right]^{0.5}, i = 1,2,3,.....m \tag{10}$$

Step 9: Calculation of TOPSIS rank index:

$$C_i^+ = \frac{d_i^-}{d_i^- + d_i^+} \tag{11}$$

Project with highest rank index C_i^+ are preferred.

5. Results and Discussion

The Project selection decision in Six Sigma implementation is a very challenging task. The project selection in initial phase of Six Sigma needed very high expertise in decision making to select right project from all given alternatives. So the hierarchical structure has been constructed in fuzzy TOPSIS decision making for the selection of right project as shown in Fig. 2.

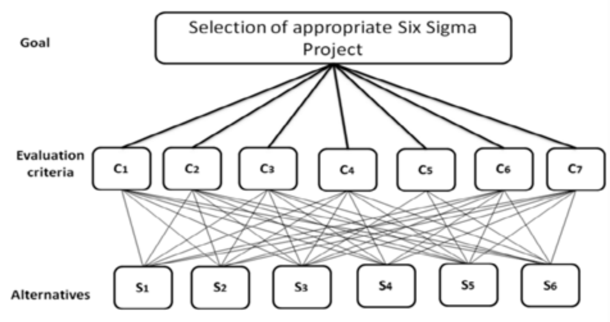

Fig. 2. The schematic hierarchy for the selection of the right Six Sigma project

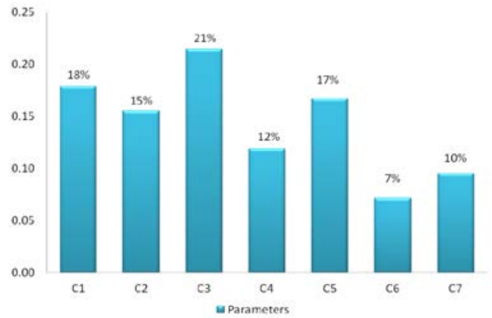

Fig. 3. Contribution of all parameters towards the selection of right Six Sigma project

This specifies our goal of the right Six Sigma project selection from the accepted six important projects (alternatives) for improvement specifies in hierarchy. The selection of right Six Sigma project depends on seven evaluation criteria (parameters) as suggested by various experts during decision making process also shows in schematic hierarchy. Alternatives are completely interdependent on these selection parameters and it shows the difficulty of the process. After these parameters are recognized, the next step is to prioritize these parameters, as to which one has higher impact on the known alternatives. MDL methodology is used to rank these parameters and for comparing these distinct parameters, numeric values are given to the parameters on a scale of 1-3 and pair-wise comparison is made. Table 1 shows the relative decision matrix formed on the basis of MDL approach and the weights are calculated for all the evaluation criteria.

Table 1
Subjective weights of the evaluation criteria calculated using MDL

Parameters	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Positive Decision	Weights	Rank
Down Time Cost(C_1)	2	3	1	3	2	3	3	15	0.179	2
Repair Time(C_2)	1	2	1	3	2	3	3	13	0.155	4
Reliability(C_3)	3	3	2	3	3	3	3	18	0.214	1
Rejection(C_4)	1	1	1	2	1	3	3	10	0.119	5
Productivity(C_5)	2	2	1	3	2	3	3	14	0.167	3
Working Environment(C_6)	1	1	1	1	1	2	1	6	0.071	7
Safety(C_7)	1	1	1	1	1	3	2	8	0.095	6

Reliability comes out as the most dominant Six Sigma project selection parameter; while working environment is found to be the least dominant parameter for selection. Contribution of all these dominating parameters towards right Six Sigma project selection is shown in bar chart (refer Fig. 3)

Table 2
Linguistic variables and corresponding fuzzy numbers

Linguistic Variable	Fuzzy number
Extremely High (EH)	(0.8, 0.9, 1.0, 1.0)
Very high (VH)	(0.7, 0.8, 0.8, 0.9)
High (H)	(0.5, 0.6, 0.7, 0.8)
Above average (AA)	(0.4, 0.5, 0.5, 0.6)
Average (A)	(0.2, 0.3, 0.4, 0.5)
Very low (VL)	(0.1, 0.2, 0.2, 0.3)
Extremely low (EL)	(0.0, 0.0, 0.1, 0.2)

In next step, comparison of all alternatives with each parameter is carried out based on fuzzy logic approach. Linguistic variables were used for the selection of right Six Sigma project. Table 2 shows the conversion of linguistic variables into fuzzy numbers for the current problem. The highest range is termed extremely high (EH) and the least is termed as extremely low (EL). A Linguistic decision matrix of alternatives for all evaluation criteria is constructed during brainstorming session with decision makers as shown in Table 3. In this case a single decision matrix has been constructed rather than having a different decision matrix for each decision maker. Fuzzy values thus obtained are finally converted into crisp values using Equation 4. Crisp values thus calculated from aggregated fuzzy ratings are shown in Table 4.

Table 3
Linguistic decision matrix of right Six Sigma project selection for all evaluation criteria

Production Shops (Alternatives)	Evaluation Criteria(Parameters)						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Metal Finishing Shop(S_1)	H	H	VL	H	VL	A	A
Shox. Machine Shop(S_2)	EH	VH	VL	EH	VL	VL	EL
Shox. Assembly Shop(S_3)	H	H	A	AA	A	AA	H
TFF Assembly Shop(S_4)	A	A	AA	VL	H	H	H
TFF Grinding Shop(S_5)	VL	A	VH	AA	VH	VH	VH
HCP Shop(S_6)	H	A	VL	H	A	VL	A

Table 4
Calculated crisp values for assigned fuzzy numbers

Production Shops (Alternatives)	Evaluation Criteria(Parameters)						
	C_1	C_2	C_3	C_4	C_5	C_6	C_7
S_1	0.6667	0.6667	0.2333	0.6667	0.2333	0.3667	0.3667
S_2	0.9444	0.8333	0.2333	0.9444	0.2333	0.2333	0.0778
S_3	0.6667	0.6667	0.3667	0.5333	0.3667	0.5333	0.6667
S_4	0.3667	0.3667	0.5333	0.2333	0.6667	0.6667	0.6667
S_5	0.2333	0.3667	0.8333	0.5333	0.8333	0.8333	0.8333
S_6	0.6667	0.3667	0.2333	0.6667	0.3667	0.2333	0.3667

Table 5
Calculated TOPSIS ranking

Production Shops (Alternatives)	TOPSIS Index	TOPSIS Rank
Metal Finishing Shop(S_1)	0.889	2
Shox. Machine Shop(S_2)	1.000	1
Shox. Assembly Shop(S_3)	0.715	4
TFF Assembly Shop(S_4)	0.139	5
TFF Grinding Shop(S_5)	0.022	6
HCP Shop(S_6)	0.778	3

Further next, obtained crisp values are analyzed with TOPSIS approach, using Eqs. (5-11) to find out the rank indices of all alternatives. Table 5 shows corresponding rank indices and ranks for all Six Sigma projects (alternatives). Our analysis shows those Shox machine shop posses higher down time cost, repair time, rejections and having lower reliability, productivity and safety, therefore this shop is selected as prime priority project for further improvement using Six Sigma strategy, as its TOPSIS rank index is highest among all selected alternatives. It is also observed that TFF grinding shop possess highest reliability and productivity at selected site (refer Table 5). We found that our results are in good agreement with of selected automotive company under normal working conditions.

6. Conclusion

In automotive sector, particularly at their shop floors, Six Sigma success rate is quite low due to higher degree of improper project selection. In this context, MADM approach has been used for selection of right Six Sigma project in an automotive industry in India. Modified digital logic (MDL) method is used to calculate weights of all influencing parameters for selection of the alternatives. Reliability has been found to be the most serious parameter whereas working environment appears as the least critical parameter. A number of alternatives have been reviewed and assessed in terms of different criteria, which are mainly responsible for considerable wastage. The priority order of alternatives is determined using fuzzy TOPSIS approach. Shox machine shop was found to be the most appropriate (right) Six Sigma Project for improvement. This study also explores the feasibility of combination of fuzzy logic with TOPSIS approach for Six Sigma project selection problem in automotive industry.

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