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AN APPRAISAL OF FACILITIES LAYOUTS USING FUZZY TOPSIS METHODOLOGY

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ABSTRACT

Evaluation of Facilities Layout alternatives to choose the best suited one for a particular type of production process is a challenging task that too when layouts involve Flexible Manufacturing System(FMS)s. The high capital outlay needed for such a layout further accentuates the seriousness of the layout making work. But moderate risk is involved in establishing it. In today's manufacturing world of JIT simple economic justification techniques are insufficient by themselves since they will have to cope with the benefits such as flexibility, higher quality, reliability and tight delivery schedules. Hence, a robust decision-making procedure for appraising Facilities Layout (FL) design alternatives urges the consideration of both economic and strategic issues. In this paper a ***Fuzzy Technique for Order Performance by Similarity to Ideal Solution (Fuzzy TOPSIS)*** *for the Multi-criteria Decision Making (MCDM) problem when there is a group of decision makers is proposed. A Fuzzy TOPSIS Approach that bases itself on the concepts of the distance measure that calculates the distance of each FL from both Fuzzy Positive Ideal Solution (FPIS) and Fuzzy negative Ideal Solution (FNIS) and that consequently establishes the Separation Measure(SM). The approach presented here enables us to incorporate subjective or qualitative data in the forms of Fuzzy Linguistic Variable (FLV)s. Trapezoidal Fuzzy Number (TRFN)s as well as crisp numbers in this FL alternatives' appraisal process. A comprehensive example illustrates the application of this method of analysis.*

KEYWORDS: *Fuzzy Linguistic Variables, Facilities Layout Selection, TOPSIS, Fuzzy Numbers.*

1. INTRODUCTION

Modern manufacturing firms need to focus on ever increasing demand for quality, degree of responsiveness to customers' demands, level of customization and all at the same time lowering costs of production to compete in the global market today. The evolution of FMS, CIM (Computer Integrated Manufacturing) has a great potential for increasing flexibility in manufacturing. The rapid emergence of areas in technology such as Robotics, Artificial Intelligence, Knowledge based systems are defintely aimed at solving various industry related day-to-day problems with little human intervention. The basis of competition has undergone a sea change, ensuring at the same time both cost effectiveness and customization in manufacturing. To ensure such a level of manufacturing, Facilities Layout (FL) holds the key. Given near equal multiple FL alternatives, we have to make use of MCDM techniques to clear all doubts about making the right choice.

2. LITERATURE SURVEY

FL selection process deals with the selection of most appropriate and effective arrangements of departments in the open continual plane to allow greater working efficiency (Apple, 1977). Due to complex and unstructured nature of FLs various approaches have been proposed by many researchers in the field. Irrespective of type of data, there is always an element of fuzziness or vagueness in the process of designing a layout (Dweiri, 1999). Karwowski and Evans, 1987 used fuzzy set theory in the field of production management very effectively and demonstrated its true potential. Deb et al. 2001 also adopted fuzzy set concepts and developed hybrid modeling for the management of Material Handling (MH) equipment, selection and planning while generating a manufacturing FL. Going further the same authors also proposed different projects of integrating FL and MH equipment selection by using a knowledge base and optimization approach. Taking a cue from the earlier works, the present work focuses on integrating various FLVs to evaluate the FL designs and make a proper selection decision.

People have strange ways of grading the subjective performance characteristics. There is inaccurate piece of information regarding the use of approximate quantitative measures such as ‘work-in-process is around 40 units, the implementation cost is nearly 50 units etc.,’ and qualitative assessments such as ‘expansion flexibility is poor, market is quite large, transportation facility is good etc.’ Such a system must effectively incorporate into the decision framework fuzzy modeling as the fuzzy approach employs FLVs that are close to common language. FLV is an effective tool to express factors such as work-in-process (WIP) level, appropriateness of a FL, flexibility, and quality of the products that are difficult to denote by using crisp numerical values.

A survey of the MCDM methods was presented by Hwang and Yoon, 1981. Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), one of the known classical MCDM methods, also was first developed by Hwang and Yoon, 1981. It bases upon the concept that the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS), i.e., the solution that maximizes the benefit criteria and minimizes the cost criteria; and the farthest from the Negative Ideal Solution (NIS), i.e., the solution that maximizes the cost criteria and minimizes the benefit criteria. In classical MCMD methods, including classical TOPSIS, the ratings and the weights of the criteria are known precisely. However, under many conditions, crisp data are inadequate to model real-life situations since human judgments including preferences are often vague and cannot estimate his preference with an exact numerical value. Lingual expressions, for example, low, medium, high, etc. are regarded as the natural representations of the judgment. These characteristics indicate the applicability of fuzzy set theory in capturing the decision makers’ preference structure. Fuzzy set theory aids in measuring the ambiguity of concepts that are associated with human being’s subjective judgment. Moreover, since in the group decision making, evaluation is resulted from different evaluator’s view of linguistic variables, its evaluation must be conducted in an uncertain, fuzzy environment. There are many examples of applications of fuzzy TOPSIS in literature (For instance: The evaluation of service quality [2]; Intercompany comparison [3]; The applications in aggregate production planning [4], Facility location selection [5] and large-scale nonlinear programming [6]). The methodology proposed in this paper can be implemented in all real-world applications of Fuzzy TOPSIS.

As far the methods for ‘selecting the best from a set of alternatives’ is concerned Liang and Wang (2004) proposed a robot selection procedure using the concepts of fuzzy set theory. In another article, Karsak and Tolga (2001) proposed a fuzzy multi-criteria decision-making (MCDM) approach for evaluating investments in advanced manufacturing systems. This method integrated economic and strategic selection criteria using a decision algorithm based on a fuzzy number ranking method. E.E.Karsak 2002 also proposed a procedure to that adopted fuzzy set theory to define linguistic variables and then used a MCDM method TOPSIS to find out the similarity to ideal solution for an FMS investment alternatives problem.

Hence, in this paper, a Fuzzy TOPSIS framework based on the concepts of distance to ideal and anti-ideal solutions using a widely appreciated MCDM methodology TOPSIS is presented for the selection of a proper FL from a set of mutually exclusive alternatives. It has proved to be one of the most robust decision aid tools that can effectively handle frequently encountered real-world problems of evaluating alternative FLs where we face fuzziness abundantly.

3. FACILITIES LAYOUT DESIGN SELECTION – A "TOPSIS" APPROACH

The selection of a particular FL from a large number of alternatives to suit a particular type of production environment is a very challenging process. Various considerations need to be taken into account in this regard. The complexity is compounded when these considerations are conflicting by nature and they have units that cannot be compared on a same common scale. TOPSIS is one of the very well established and popular multi-criteria decision-making techniques with a sound logical and rational basis. It gives very dependable result. Perhaps, after AHP this methodology has been most widely adopted for various applications. As the real-world problems are complicated, convoluted and interwoven with many parameters, any technique that handles only crisp data will be of little help in depicting the real situation. Hence, a good technique must be capable of handling vague and imprecise data as well. Fuzzy logic when accompanies TOPSIS, the methodology becomes robust and strong to tackle the real problems. This article deals with such a methodology that used Fuzzy-TOPSIS with a good demonstratable example.

3.1 Madm Method

"Technique for Order Preference by Similarity to Ideal Solution" (TOPSIS) [25], has been adopted here. A problem is considered as a MCDM problem if and only if there appear at least two conflicting criteria and there are at least two alternative solutions.

The Following are the Features of the MADM Method:

i. it should have a set of quantifiable objectives.

ii. it should possess a set of well-defined constraints.

iii. it should have a process to obtain some tradeoff information between the stated and unstated objectives.

MADM comprises of many methods. The selection of a particular MADM method used for a particular problem is also a MADM problem. Every MADM problem may use more than one method to suit the problem.

A MADM problem can be expressed in matrix form. In MADM, a decision matrix 'D' is a (m x n) matrix whose element v(i,j) indicates value of alternative i(A_i) for the attribute j (x_j) where 'm' alternatives and 'n' attributes are there. Thus A_i (where i = 1,2,3 . . .m) is denoted by A_i = (v (i, 1), v(i,2), v(i,3), . . .v(i,m)) and X_i = (v (1,j), v(2,j), v(3,j),. . . v(n,j))^T. The structure of 'D' matrix is shown in Table 4.2.1.

Table 4.2.1: Decision Matrix

Attributes		X1	X2	X3		Xn
Alternative Layouts	FL_1	v_{11}	v_{12}	v_{13}		v_{1n}
	FL_2	v_{21}	v_{22}	v_{23}		v_n
	FL_3	v_{31}	v_{32}	v_{33}		v_n
	FL_m	v_{m1}	v_{m2}	v_{m3}		v_{mn}

The conflicting criteria in MADM are shown in the fig. 2(a), 2(b).

Table 4.2.2(a): Conflicting

	X1	X2
L1	100	500
L2	300	400

Table 4.2.2(a): Conflicting

	X1	X2
L1	100	500
L2	70	400

The example shown in Fig 4.2.2(a) is conflicting as a high point in (L_2X_1) combination compared to (L_1X_1) combination is taken with a low point in the (L_2X_2) combination compared to (L_2X_1).

4. PROBLEM DEFINITION

Suppose a committee of 'k' decision makers (DM_1, DM_2, . . . DM_k) employs one or more rating sets to evaluate the preferences. These decision makers are responsible for assessing the appropriateness of 'm' alternatives (FL_1, FL_2, . . . FL_m) on the basis of each of 'n' criteria (C_1, C_2, . . . C_n) governing each of the alternatives and also on the basis of 'importance' of each of the criteria. Let S_{ijt} be the importance rating assigned to alternative FL_i by the decision-maker D_j for the criterion C_t. Let W_{tj} be the importance weight given to criterion C_t, by the decision-maker D_j. Thus, the committee has to first aggregate the ratings S_{ijt} of k decision makers for each alternative FL_i versus each criterion C_t, to form the rating S_{it}. Each aggregated S_{it}, for all i = 1, 2, . . , m; t = 1, 2, . . . , n, can further be weighted by a weight W_{tj} according to the relative importance of the n criteria. Then, Closeness ratio for each FL d_i^+ and d_i^- are calculated using TOPSIS method and finally, the Closeness rating or FFLPI is calculated and they are ranked to help choose the most suited one.

4.1 Procedural Steps

Step 1: Identify 'n' criteria **(C_1 – C_n)**, 'm' alternatives **(FL_1 – FL_m)** and 'k' decision makers **(DM_1 – DM_k)**. This will have expressed in matrix form as Decision Matrix.

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \dots\dots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \dots\dots & \tilde{x}_{2n} \\ \dots & \dots & \dots\dots & \dots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \dots\dots & \tilde{x}_{mn} \end{bmatrix}, \quad i = 1,2,\dots\dots,m; \; j = 1,2,\dots\dots,n \tag{1}$$

Step 2: Develop the scale of weights 'W' to assess each of the criterion for its importance by the DMs **(Table 4.2.1)**

Step 3: Collect the subjective ratings of individual DMs with reference to the importance of each criterion **(Table 4.2.2)**

Step 4: Calculate aggregate Fuzzy Importance Weights of each criteria using $\tilde{w}_j = \frac{1}{k}\left(\tilde{w}_j^1 + \tilde{w}_j^2 + \dots\dots + \tilde{w}_j^k\right)$ (2) and find out Crisp Performance (CP) values.

Step 5: Develop the scale of rating 'S' to assess each alternative's performance in relation to the criteria by the DMs **(Table 4.2.4)**

Step 6: Ascertain DMs' assessment of each of the alternative FLs with reference to each criterion. **(Tables 4.2.5-9)**

Step 7: The fuzzy performance ratings of each of the alternatives regarding the criteria are averaged to synthesize individual DM's judgments using $\tilde{x}_{ij} = \frac{1}{k}\left(\tilde{x}_{ij}^{1} + \tilde{x}_{ij}^{2} + \dots\dots + \tilde{x}_{ij}^{k}\right)$ **(Table 4.2.10)**

Step 8: Normalize fuzzy decision matrix using $\tilde{R} = \left[\tilde{r}_{ij}\right]_{mXn}, \; i = 1,2,..,m; \; j = 1,2,\dots,n$.(3)

(Table 4.2.11)

where $\tilde{r}_{ij} = \left(\frac{a_{ij}}{c_j^+}, \frac{b_{ij}}{c_j^+}, \frac{c_{ij}}{c_j^+}\right); c_j^+ = \max_i c_{ij}$ (4)

Step 9: Construct weighted normalized fuzzy decision matrix using $\tilde{D} = \left[\tilde{v}_{ij}\right]_{mxn}$, i=1,2,..,m; j=1,2,…n

where $\left[\tilde{v}_{ij}\right] = \left[\tilde{r}_{ij} \otimes \tilde{w}_j\right]$ **(Table 4.2.12)**

Step 10: As **the** FPIS and FNIS are within the interval [0,1] we have $A^{+} = \left[\tilde{v}_1^{+}, \tilde{v}_2^{+}, ...\tilde{v}_n^{+}\right]$ and $A^{-} = \left[\tilde{v}_1^{-}, \tilde{v}_2^{-}, ...\tilde{v}_n^{-}\right]$ respectively, where $\tilde{v}_j^{+}$ = (1, 1, 1) and $\tilde{v}_j^{-}$ = (0, 0, 0) ; j=1,2,…,n.

Step 11: Calculate the Separation Measures of each FL to FPIS and FNIS respectively by using $SM_i^{+} = \sum_{j=1}^{n} SM\left(\tilde{v}_{ij}, \tilde{v}_{ij}^{+}\right)$, i=1,2,….m; j=1,2,…n and $SM_i^{-} = \sum_{j=1}^{n} SM\left(\tilde{v}_{ij}, \tilde{v}_{ij}^{-}\right)$, i=1,2,….m; j=1,2,…n.

Step 12: Obtain the Closeness ratio CR and rank the alternatives in descending order by using

$$\mathrm{CR}_i^{*} = \frac{\mathrm{SM}_i^{-}}{\mathrm{SM}_i^{+} + \mathrm{SM}_i^{-}},\quad i = 1, ..., m \quad where \;\; 0 \le CR_i^{*} \le 1$$

4.2 CASE STUDY

Considering the fuzziness in the decision data and group decision making process, linguistic variables are used to assess the weights of all criteria and the ratings of each alternative with respect to each criterion. It is possible to convert the decision matrix into a fuzzy decision one and construct a weighted normalized fuzzy decision matrix once the decision makers' fuzzy ratings have been pooled. According to the concept of TOPSIS, we define the Fuzzy Positive Ideal Solution (FPIS) and the Fuzzy Negative Ideal Solution (FNIS). Then, we use a new method to calculate the distance between two triangular fuzzy ratings. Using the idea of comparison between two fuzzy numbers, we calculate the distance of each alternative from FPIS and FNIS, respectively. In other words a new distance measure for Fuzzy TOPSIS is proposed in this paper. Finally, a closeness coefficient of each alternative is used to determine the ranking order of all alternatives. The higher value of closeness coefficient indicates that an alternative is closer to FPIS and farther from FNIS simultaneously.

In this article a group of 4 DMs considering 5 criteria will have to make a decision to choose one best FL from amongst 5 alternatives. To do this they will have to first attach importance weights to each of the criteria individually and then evaluate each of the FL alternatives with reference to criteria separately and then find out closeness ratio of each FL alternative. To accomplish this, first distances from Fuzzy Positive Ideal Solution (FPIS) and Fuzzy Negative Ideal Solution (FNIS) are found for each alternative. Thus, the problem has **4 decision makers (DM_1–DM_4), 5 Criteria under consideration (C_1–C_5) for 5 FL alternatives (FL_1–FL_5)**. The Evaluation within the FL selection process is mainly from the perspective of its parameters. All the parameters will have to be addressed simultaneously. Here, trapezoidal fuzzy number (TRFN)s of the form (a_i, b_i, c_i, d_i) are used for its ease of handling and understanding. This study was conducted at a sophisticated tool room in Bangalore and results found were very encouraging. The LVs used are simple and most commonly used in fuzzy logic.

Table 4.2.1: Scale of fuzzy linguistic rating 'W' for Importance of Criteria

Linguistic Variable (LV)s	Corresponding TRFNs
Very Low (VL)	(0, 0, 0, 0.2)
Low (L)	(0, 0.2, 0.2, 0.4)

Medium (M)	(0.1, 0.5, 0.5, 0.8)
High (H)	(0.5, 0.7, 0.7, 1)
Very High (VH)	(0.6, 1, 1, 1)

Table 4.2.2: Linguistic Rating for each Criterion by the DMs

Criteria	Decision Makers			
	DM_1	DM_2	DM_3	DM_4
Capacity (C_1)	M	VH	M	H
Layout Flexibility (C_2)	H	VH	VH	M
Bottlenecks (C_3)	VH	H	H	VH
Quality Standard Adherence(C_4)	VH	H	VH	VH
Supply-Demand Requirement (C_5)	VL	L	H	VH

Table 4.2.3: Fuzzy Importance Ratings, CP values and Ranking of each criterion [CP Values – Crisp Performance Values]

Criteria	Fuzzy Rating	CP values	Rank
Performance Values]			
C_1	(0.325, 0.675, 0.675, 0.900)	0.6438	4
C_2	(0.450, 0.800, 0.800, 0.950)	0.7500	3
C_3	(0.550, 0.850, 0.850, 1.000)	0.8125	2
C_4	(0.575, 0.925, 0.925, 1.000)	0.8563	1
C_5	(0.275, 0.475, 0.475, 0.650)	0.4688	5

Table 4.2.4: Scale of fuzzy linguistic rating 'S' for each alternative W.R.T to criteria

Linguistic Variable (LV)s	Corresponding TRFNs
Very Poor (VP)	(0, 0, 0, 0.35)
In between VP & P (VPAP)	(0, 0, 0.3, 0.45)
Poor (P)	(0, 0.2, 0.2, 0.5)
In between P & F (PAF)	(0, 0.3, 0.5, 0.8)
Fair (F)	(0.3, 0.5, 0.5, 0.9)
In between F & G (FAG)	(0.3, 0.5, 0.8, 1)
Good (G)	(0.6, 0.8, 0.8, 1)
In between G & VG (GAVG)	(0.6, 0.8, 1, 1)
Very Good (VG)	(0.9, 1, 1, 1)

Table 4.2.5 : Preference weights by DMs for FLs using 'S' for Criterion 1

Alternative FLs	Decision Makers			
	DM1	DM2	DM3	DM4
FL_1	VPAP	F	PAF	FAG
FL_2	FAG	PAF	F	G
FL_3	PAF	GAVG	PAF	FAG
FL_4	FAG	PAF	G	F
FL_5	GAVG	VG	FAG	F

Table 4.2.6 : Preference weights by DMs for FLs using 'S' for Criterion 2

Alternative FLs	Decision Makers			
	DM1	DM2	DM3	DM4
FL_1	PAF	F	P	F
FL_2	G	FAG	PAF	VG
FL_3	PAF	FAG	P	F
FL_4	GAVG	G	FAG	PAF
FL_5	FAG	G	PAF	FAG

Table 4.2.7 : Preference weights by DMs for FLs using 'S' for Criterion 3

Alternative FLs	Decision Makers			
	DM1	DM2	DM3	DM4
FL_1	G	G	G	FAG
FL_2	PAF	F	GAVG	G
FL_3	FAG	P	FAG	VG
FL_4	GAVG	FAG	PAF	FAG
FL_5	G	FAG	PAF	F

Table 4.2. 8 : Preference weights by DMs for FLs using 'S' for Criterion 4

Alternative FLs	Decision Makers			
	DM1	DM2	DM3	DM4
FL_1	PAF	F	GAVG	P
FL_2	FAG	P	VPAP	G
FL_3	G	FAG	PAF	F
FL_4	F	VG	FAG	PAF
FL_5	VPAP	F	G	FAG

Table 4.2.9 : Preference weights by DMs for FLs using 'S' for Criterion 5

Alternative FLs	Decision Makers			
	DM1	DM2	DM3	DM4
FL_1	VPAP	F	PAF	FAG
FL_2	FAG	PAF	F	G
FL_3	PAF	GAVG	PAF	FAG
FL_4	FAG	PAF	G	F
FL_5	GAVG	VG	FAG	F

Table 4.2.10: Fuzzy Decision Matrix of 5 FLs for each Criterion

C	FL1	FL2	FL3	FL4	FL5
C_1	(0.150,0.325,0.525 ,0.788)	(0.300,0.525,0.650 ,0.925)	(0.225,0.475,0.700, 0.900)	(0.300,0.525,0.650, 0.925)	(0.450,0.625,0.750, 0.825)
C_2	(0.150,0.375,0.425 ,0.775)	(0.450,0.650,0.775 ,0.950)	(0.225,0.425,0.500, 0.825)	(0.375,0.600,0.775, 0.950)	(0.300,0.400,0.725, 0.950)
C_3	(0.525,0.725,0.800 ,1.000)	(0.375,0.600,0.700 ,0.925)	(0.375,0.550,0.700, 0.875)	(0.300,0.525,0.775, 0.950)	(0.300,0.525,0.650, 0.925)
C_4	(0.275,0.450,0.550 ,0.800)	(0.225,0.375,0.525 ,0.738)	(0.300,0.525,0.650, 0.925)	(0.375,0.575,0.700, 0.925)	(0.300,0.450,0.600, 0.838)
C_5	(0.150,0.325,0.525 ,0.788)	(0.300,0.525,0.650 ,0.925)	(0.225,0.475,0.700, 0.900)	(0.300,0.525,0.650, 0.925)	(0.450,0.625,0.750, 0.825)

Table 4.2.12: Fuzzy weighted Normalised Decision Matrix of FLs

C	FL1	FL2	FL3	FL4	FL5
C_1	(0.053,0.237,0.383,0.766)	(0.105,0.383,0.474,0.900)	(0.079,0.346,0.511,0.876)	(0.105,0.383,0.474,0.900)	(0.158,0.456,0.547,0.803)
C_2	(0.071,0.316,0.358,0.775)	(0.213,0.547,0.653,0.950,)	(0.107,0.358,0.421,0.825)	(0.178,0.506,0.653,.0.950)	(0.142,0.337,0.610,0.950)
C_3	(0.289,0.616,0.680,1.000)	(0.206,0.510,0.595,0.925)	(0.206,0.468,0.595,0.875)	(0.165,0.446,0.659,0.950)	(0.178,0.446,0.552,0.925)
C_4	(0.171,0.450,0.550,0.865)	(0.140,0.375,0.525,0.797)	(0.186,0.524,0.650,1.000)	(0.233,0.575,0.700,1.000)	(0.186,0.450,0.600,0.905)
C_5	(0.045,0.167,0.269,0.553)	(0.089,0.269,0.333,0.650)	(0.067,0.244,0.360,0.632)	(0.089,0.269,0.333,0.650)	(0.134,0.321,0.385,0.580)

The FPIS and FNIS values are as shown below:

- A^+ = [(1,1,1,1), (1,1,1,1), (1,1,1,1), (1,1,1,1), (1,1,1,1)] and
- = [(0,0,0,0), (0,0,0,0), (0,0,0,0), (0,0,0,0), (0,0,0,0)]

Table 4.2.13: Separation Measures, Closeness Ratio and Rank of the alternatives

FLs	SMi+	SMi-	CRi	Rank
FL_1	3.111	2.481	0.4437	5
FL_2	2.889	2.717	0.4847	3
FL_3	3.198	2.667	0.4547	4
FL_4	2.809	2.884	0.5066	1
FL_5	2.877	2.709	0.4849	2

5. CONCLUSION AND INFERENCE

Therefore, the proximity index or the Closeness Ratio (CR) in the ascending order is $CR_4 > CR_5 > CR_2 > CR_3 > CR_1$. Hence FL_4 having the largest CR value is the best suited layout for the production system under study and thus it can be selected.

The study considers the perception of individual expert with reference to each criterion and alternative. The weight calculation is a crucial step which can be achieved by many methods including eigen vector method, entropy method, WSM, WPM or linear programming for multi-dimensions of analysis preference (LINMAP) and other methods and all are equally acceptable. The normalization procedure for raw data helps in eliminating anomalies with different measurement units and scales in several MCDM problems. However, the linear scale transform process adopted in this article is to preserve the property that the ranges of normalized TRFNs to be included in [0,1]. The distances found out from both FPIS and FNIS doubly ensure the correctness of the methodology. The subjectivity brought into the study by way of adopting fuzzy logic with TOPSIS has definitely improved the decision quality.

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