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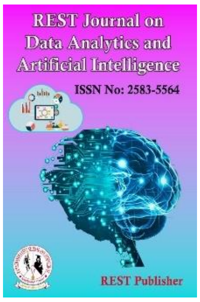

Fuzzy Taxonomy Based Optimal Decision Making on Construction Materials

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Abstract: *Decision making on material selection is quite an inevitable task in the construction industry. This research work discusses the taxonomy method of decision making under a fuzzy environment. A decision-making model is developed to make optimal selection of construction materials based on five core criteria. The representations using fuzzy facilitates flexible decision making in material selection-based problems. A decision matrix with linguistic values representing the criterion satisfaction of the alternatives is subjected to the proposed method of fuzzy taxonomy to derive the optimal ranking results of the construction materials that are considered as the alternatives. The consistency of the ranking results using fuzzy taxonomy is found to be more consistent when compared with other fuzzy based decision-making methods. The efficiency of fuzzy representations is more promising and this will definitely support the decision makers to endure the hurdles and commotions in material selection.*

Keywords: *Fuzzy Taxonomy, optimal decision making, construction materials.*

1. INTRODUCTION

Construction industry is one of the biggest sectors and it performs the skillful art of erecting buildings of varied kinds. The longevity of the constructions made are highly dependent on the material inputs. It is essential to make intense study on different properties of the construction materials such as physical, mechanical, chemical, electrical, magnetic and thermal. The withering of the buildings and collateral damages are the result of the external environmental factors. In recent times, the construction industries are switching to more robust building materials. The heavy nature materials are replaced with light weighted ones and also these industries prefer green construction materials. As several kinds of construction materials are flooded in the markets, the construction industries are constrained with the choice making problem of the materials. How can these industries make optimal decisions on construction materials? One of the simplest and viable ways of making ideal decisions is applying multi criteria decision making methods. A decision-making process involves the process of finding the best solution to the problems bound with criteria. Many of the decision-making problems are ranking based and the preferences are given to the alternatives depending on criterion satisfaction. The act of choosing apt decision-making methods is depending on the nature of the attributes, number of decision makers and many other factors. This research work addresses the decision-making problem of construction materials based on significant attributes of mechanical properties of materials. The decision-making method of Taxonomy is applied in a fuzzy sense to choose materials based on some of the significant criteria. The remainder of the contents are organized as follows: section 2 presents the state of art of review in the dimensions of MCDM applications in construction industries, Taxonomy MCDM applications and research gaps. Section 3 sketches the steps involved in Fuzzy Taxonomy MCDM. Section 4 applies the proposed method in decision making on construction materials. Sensitivity analysis is made in section 5 and the last section concludes the work with industrial applications and future research directions.

2. LITERATURE REVIEW

This section is segmented into three divisions. The first segment presents a detailed review of the recent applications of MCDM in construction industries. The second segment describes the applications of Taxonomy MCDM in making optimal decisions. The last segment identifies the research work, motivation and background of the study. The methods of MCDM are applied in the construction industry especially in the contexts of supplier selection, construction site selection, materials selection and supply chain management. Singh et al [22], Shanmugam et al [21], Alam et al [3] applied hybrid MCDM methods in supplier selection. Karamoozia et al [17] employed fuzzy decision making in green supplier selection. Tushar et al [27] focussed on circular supplier selection. Banihashemi et al [6] used fuzzy Best and Worst methods in green supply chain management. Soufi et al [25] discussed the drivers of green supply chain management. Khan et al [18] deliberated on supply chain enablers. Iqbal et al [16] applied the ISM-MICMAC approach in analysing critical factors of the supply chain. Bathrinath et al [7] used fuzzy AHP-WASPAS to make optimal decisions on construction sites. Donbosco et al [8] applied a rough neutrosophic matrix. Li et al [19] employed sustainability indexes of green building. Siraj et al [23] investigated the construction projects using hybrid MCDM. Gaur et al [10] made assessments on stakeholders using the method of CRITIC-TOPSIS. Zolin et al [26] and Nickdoost et al [20] integrated big data analytics in the decision-making process. Afaneh [2] integrated mixed reality technology to the decision-making process. In addition to above-mentioned decision-making problems in construction industry, Alone et al [5] discoursed on performance assessment, Aditia et al [1] modelled cost optimization using EDAS-CRITIC methods, Fathima et al [9] applied AHP to discourse on partnerships of construction industry. Soni et al [24] applied integrated MCDM in making selection of building materials, The MCDM methods find extensive applications in making optimal decisions on various facets of the construction industry. Some of the most commonly applied MCDM methods are AHP, CRITIC to determine the criterion weights. The method of TOPSIS is predominantly used in ranking alternatives and moreover MCDM methods of different combinations are applied. Taxonomy is a MCDM method developed by Adanson in 1763.[4] The contributions of a mathematical crew of Poland facilitated the expansion of this method. Hellwing applied this method in classifying and estimating the rate of development. Hellwig [11-15] applied this method in typological divisions of countries and to evaluate manpower. This method of Taxonomy is more advantageous as it is one of the compensatory methods used to handle qualitative data and independent criteria. Also, the alternatives are ranked based on comparison with one another. From the above-mentioned literature, the following research gaps are identified.

1. The method of Taxonomy has not been discussed under a fuzzy environment.
2. The decision-making problem on construction material selection is not modelled using the Taxonomy method.
3. Decision making problems on construction material selection are very limited

This has motivated the authors to design a fuzzy taxonomy-based decision-making model to make optimal decisions on construction material selection.

3. METHODOLOGY OF FUZZY TAXONOMY

This section briefly presents the steps involved in Fuzzy Taxonomy MCDM based on the conventional Taxonomy method [4].

1. **Step I:** Problem Definition and deciding the alternatives cum criteria of decision making
2. **Step II:** Formulation of decision making matrix of order l × h with linguistic variables in each cells.

$$D = \begin{bmatrix} Lx_{11} & \cdots & Lx_{1l} \\ \vdots & \ddots & \vdots \\ Lx_{l1} & \cdots & Lx_{lh} \end{bmatrix} \quad \text{l=1, 2…r,} \quad h = 1,2,\ldots s$$

Step III: Convert each of the linguistic variables i.e the qualitative expression to quantitative values using any of the fuzzy number representations

$$\widetilde{D} = \begin{bmatrix} fx_{11} & \cdots & fx_{1l} \\ \vdots & \ddots & \vdots \\ fx_{l1} & \cdots & fx_{lh} \end{bmatrix}$$

Step IV: Compute the mean and standard deviation of each of the alternatives

$$\text{Mean } M_s = \frac{1}{r}\sum_{l=1}^{r} fx_{lh} \quad h = 1,2,..s \qquad (3.1)$$

Standard Deviation $SD_s = \sqrt{\frac{1}{r}\sum_{l=1}^{r}(fx_{lh} - M_s)^2} \quad h = 1,2,..s$ (3.2)

Step V: Construct the standard matrix G, where $G_{lh} = \frac{fx_{lh} - M_s}{SD_s}$ (3.3)

$$G = \begin{bmatrix} G_{11} & \cdots & G_{1l} \\ \vdots & \ddots & \vdots \\ G_{l1} & \cdots & G_{lh} \end{bmatrix}$$

Step VI: Determine the Composite Distance matrix
In this step the alternatives say u and v are compared and each cell value is obtained using

$$C_{uv} = \sqrt{\sum_{h=1}^{s}(G_{us} - G_{vs})^2} \qquad (3.4)$$

Step VII: Find the minimal values in each row and find the mean cum standard deviation. This step is referred as homogenizing of the alternatives.
Step VIII: Determine the development pattern C_{u0} by repeating the Step VI to the ideal values identified in the standard matrix with respect to each of the criteria.
Step IX: The development attribute A_l is determined,

where $A_l = \frac{C_{u0}}{C_0}$, where $C_o = \overline{C_{uo}} + 2SC_{uo}$ (3.5)

Step X: The alternatives are ranked based on the values of $A_{l,} 0 < A_l < 1$. Closer to 0, alternatives are given first priority and values to closer to 1 are given least priority.

4. APPLICATION OF THE FUZZY TAXONOMY IN SELECTING CONSTRUCTION MATERIALS

In this section, the method proposed in section 3 is applied in selecting construction materials. The criteria chosen for this problem is presented in Table 4.1.

TABLE 1. Description of Criteria

Criteria	Definition
Strength (S)	Potential to withstand debacles
Hardness (H)	Ability to endure deformation
Elasticity (E)	Competency to regain the physical topographies
Thermal capacity (TC)	Capability of heat absorption
Abrasion Resistance (AR)	Tendency of preventing loss of material due to particle rubbing

The decision-making model is constructed with ten different kinds of construction materials as alternatives. The initial decision-making matrix with linguistic values is as follows

	S	H	E	TC	AR
CM1	M	M	H	M	L
CM2	L	VL	M	L	M
CM3	H	M	M	H	M
CM4	VH	H	M	M	L
CM5	H	M	M	H	M
CM6	M	M	M	H	M
CM7	VL	L	M	M	H
CM8	L	M	VH	H	M
CM9	M	L	L	M	L
CM10	H	M	L	M	M

Using the triangular fuzzy number representation, the linguistic values are quantified as follows using Table 4.2

	S	**H**	**E**	**TC**	**AR**
CM1	0.64	0.64	0.76	0.64	0.36
CM2	0.36	0.13	0.64	0.36	0.64
CM3	0.76	0.64	0.64	0.76	0.64
CM4	0.95	0.76	0.64	0.64	0.36
CM5	0.76	0.64	0.64	0.76	0.64
CM6	0.64	0.64	0.64	0.76	0.64
CM7	0.13	0.36	0.64	0.64	0.76
CM8	0.36	0.64	0.95	0.76	0.64
CM9	0.64	0.36	0.36	0.64	0.36
CM10	0.76	0.64	0.36	0.64	0.64

TABLE 2. Triangular fuzzy numbers & Linguistic Values

Qualitative Values	**Quantitative Values**
Very Low	0.13
Low	0.36
Medium	0.64
High	0.76
Very High	0.95

The Mean and Standard deviation presented in Table 4.3 is obtained using the step IV

TABLE 3. Mean and Standard Deviation

M_s	0.6	0.557	0.627	0.66	0.568
SD_s	0.244994	0.204616	0.171791	0.121106	0.148234

The standard matrix is obtained using the step V

	S	**H**	**E**	**TC**	**AR**
CM1	0.163269	0.405638	0.774196	-0.16514	-1.40319
CM2	-0.97961	-2.08683	0.075673	-2.47717	0.485718
CM3	0.653076	0.992101	0.075673	0.825723	0.485718
CM4	1.428604	0.992101	0.075673	-0.16514	-1.40319
CM5	0.653076	0.405638	0.075673	0.825723	0.485718
CM6	0.163269	0.405638	0.075673	0.825723	0.485718
CM7	-1.91841	-0.96278	0.075673	-0.16514	1.295249
CM8	-0.97961	0.405638	1.880189	0.825723	0.485718
CM9	0.163269	-0.96278	-1.55421	-0.16514	-1.40319
CM10	0.653076	0.405638	-1.55421	-0.16514	0.485718

The composite distance matrix is determined using step VI

	CM1	**CM2**	**CM3**	**CM4**	**CM5**	**CM6**	**CM7**	**CM8**	**CM9**	**CM10**
CM1	0	4.113386	2.370984	1.559791	2.297308	2.244485	3.738374	2.660674	2.700749	3.037985
CM2	4.113386	0	4.801522	4.918615	4.448279	4.292748	2.854056	4.514176	3.760269	4.108537
CM3	2.370984	4.801522	0	2.269631	0.586464	0.764101	3.474372	2.503177	3.35675	1.995566
CM4	1.559791	4.918615	2.269631	0	2.344176	2.548488	4.722883	3.734905	2.842385	2.677662
CM5	2.297308	4.448279	0.586464	2.344176	0	0.489807	3.181552	2.433507	3.052667	1.907445
CM6	2.244485	4.292748	0.764101	2.548488	0.489807	0	2.800556	2.135992	3.013116	1.969329
CM7	3.738374	2.854056	3.474372	4.722883	3.181552	2.800556	0	2.765382	3.777761	3.434673
CM8	2.660674	4.514176	2.503177	3.734905	2.433507	2.135992	2.765382	0	4.418556	2.383366
CM9	2.700749	3.760269	3.35675	2.842385	3.052667	3.013116	3.777761	4.418556	0	2.383366
CM10	3.037985	4.108537	1.995566	2.677662	1.907445	1.969329	3.434673	2.383366	2.383366	0

Using the step VII-X, the ten alternatives are ranked as follows in Table 4.4

TABLE 4. Ranking of the Alternatives

CM1	**CM2**	**CM3**	**CM4**	**CM5**	**CM6**	**CM7**	**CM8**	**CM9**	**CM10**
5	10	3	6	2	1	9	7	8	4

5. SENSITIVITY ANALYSIS

This section tests the consistency of the ranking results obtained using the method of fuzzy taxonomy with other commonly used MCDM methods. The Table 5.1 presents the ranking results using different MCDM methods.

Alternatives	**CM1**	**CM2**	**CM3**	**CM4**	**CM5**	**CM6**	**CM7**	**CM8**	**CM9**	**CM10**
Fuzzy Taxonomy (FT)	5	10	3	6	2	1	9	7	8	4
AHP-TOPSIS (ATO)	5	10	3	6	2	1	8	7	9	4
CRITIC-TOPSIS (CTO)	6	10	3	6	2	1	8	7	9	4
Equal Weight-TOPSIS (EWTO)	5	10	2	6	3	1	9	7	8	4

The following table 5.2 represents the correlation coefficient between the ranking results obtained in Table 5.1

TABLE 5. Comparison of ranking results

	FT	ATO	CTO	EWTO
FT		0.987879	0.982413765	0.987879
ATO			0.99454233	0.975757576
CTO				0.9702852
EWTO				

It is observed that the ranking results are more consistent with the ranking results of other MCDM methods. The fuzzy taxonomy method doesn't employ the criterion weights directly but utilizes the nature of the criteria. Hence the efforts on computing criterion weights are almost not required in this method. This is one of the advantages of using fuzzy taxonomy.

6. CONCLUSION

This article has discussed the MCDM method of Taxonomy in a fuzzy environment. The application of fuzzy taxonomy in making optimal decisions on construction materials is one of the significant aspects of this research work. But the example considered for testing the efficacy of the proposed method is hypothesized, which is one of the limitations of this work. However, this research work has more industrial implications with special reference to the construction industry. The decision making approach developed in this paper resolves the hurdles of making optimal decisions with linguistic feedback of the experts. It is easier to solve ranking based problems with quantitative inputs than with qualitative representations. Hence this fuzzy based taxonomy MCDM method will be more suitable and compatible to make optimal decisions. This approach shall also be applied to handle such similar kinds of problems associated with other industrial sectors.

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