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Integrated Fuzzy (GMM) -TOPSIS Model for Best Design Concept and Material Selection Process

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Abstract*:* Design concept is an important wealth-creating activity in companies and infrastructure. However, the process of designing is very complex. Besides, the information required during the conceptual stage is incomplete, imprecise, and fuzzy. Selection of proper materials for a diverse mechanism is one of the hardest tasks in the design and product improvements in various industrial applications. A systematic and efficient approach towards conceptual design and material selection is necessary in order to select the best alternative for a given engineering application. The selection of an optimal design of product and material selection for an engineering design from among many alternatives on the basis of many attributes is a multiple criteria decision making (MADM) problem. This paper proposes an integrated decision-making approach based on fuzzy linguistic variables and geometric mean method integrated with TOPSIS (technique for order performance by similarity to ideal solution) framework. The model will help designers and engineers to reach a consensus on design and materials selection for a specific application. Verification of the model is demonstrated with two example problems from the literature and results are compared with other models. Two real life problems are cited in order to demonstrate and validate the effectiveness and flexibility of the model.

Keywords: Design concept, Material selection, Multi Criteria Decision Making (MCDM), Geometric Main Method (GMM), technique for order performance by similarity to ideal solution (TOPSIS).

I. INTRODUCTION AND REVIEW

I.I. INTRODUCTION

Conceptual design of mechanical system is the first and key stage of a product lifecycle. Because every stage of product design follows the process of design-evaluation-redesign, the selection and evaluation of the feasible scheme is of great importance. However, the process of designing is very complex and not well understood, and the information managed during the conceptual stage is incomplete, imprecise, and vague. Within this stage, several design solutions have to be generated, correctly evaluated and selected. Therefore, how to select the ‘‘best” design concept from a set of concept variants is a multiple criteria decision making problem (MCDM) as presented by Chen and Fodor [1,2]. Design engineers need to consider not only the required functionality, but also other life-cycle criteria (e.g., manufacturability, reliability, assembability, maintainability, etc.) of a product. Each alternative of design concept has each of the product criteria to meet the required performance. Designers have to take into account all the criteria and their relative weights (relative importance levels) for the expected performance of each alternative.

I.II. CONCEPTUAL DESIGN

According to Ashby et al. [3] achieving the match with design requirements involves four fundamental steps. (1) A way for translating design necessities into a requirement for material and process. (2) A method for screening out those that cannot meet the specification, leaving a subset of the original menu. (3) A method for ranking the surviving materials and process, identifying those that have the best potential. (4) An approach of searching for supporting information about the top-ranked candidates, giving as much background information about their strengths, weaknesses, history of use and future potential as possible. The authors also pointed that; implementing multi -materials in product design leads to higher product performance in terms of functionality, manufacturability, costs and aesthetics.

Multi-material selection is considered as one of the design strategies implemented to attain product efficiency according to Wang [4]. Each product is different, and therefore several products may require numerous functions that could not be satisfied by utilizing a single material. A design that incorporates multi-material selection is a feasible alternative in order to achieve the functional requirements of a product. Novita S., et. al. [5],Presents a MCDM for material selection during the conceptual design phase and applied on an automotive body assembly. J.C. Albiána, C. Vila [6] draw up a framework proposal for integrated material and process selection in product design. Fuzzy multi-criteria decision making (MCDM) approach is proposed to select the best prototype product by Hao-Tien Liu [7]. Kuo-Chen Hung et. al. [8] presents a fuzzy integrated approach to assess the performance of design concepts. A new integrated design concept evaluation approach based on vague sets is presented by Xiuli Geng et. al. [9].Hambali Ariff et. al. [10], presents the methodology of selecting design concepts using analytical hierarchy process.

I.III. MATERIAL SELECTION

An ever increasing variety of materials is available today, with each having its own characteristics, applications, advantages, and limitations. When selecting materials for engineering designs, a clear understanding of the functional requirements for each individual component is required and various important criteria or attributes need to be considered. Material selection attribute is defined as an attribute that influences the selection of a material for a given application. These attributes include: physical properties, electrical properties, magnetic properties, mechanical properties, chemical properties, manufacturing properties (machinability, formability, weld ability, cast ability, heat treatability, etc.), material cost, product shape, material impact on environment, performance characteristics, availability, fashion, market trends, cultural aspects, aesthetics, recycling, target group, etc.

The selection of an optimal material for an engineering design from among two or more alternative materials on the basis of two or more attributes is a multiple criteria decision making (MCDM) problem. The selection decisions are complex, as material selection is more challenging today. There is a need for simple, systematic, and logical methods or mathematical tools to guide decision makers in considering a number of selection attributes and their interrelations. The objective of any material selection procedure is to identify appropriate selection attributes, and obtain the most appropriate combination of attributes in conjunction with the real requirement. Thus, efforts need to be extended to identify those attributes that influence material selection for a given engineering design to eliminate unsuitable alternatives, and to select the most appropriate alternative using simple and logical methods, [3].

Chiner [11] proposed five steps for material selection: definition of design, analysis of material properties, screening of candidate materials, evaluation and decision for optimal solution, and verification tests. Farag [12] on his handbook for material selection described the different stages of design and the related activities of the material selection. Farag defined three stages of selection: namely initial screening, developing and comparing alternatives, and selecting the optimum solution. Moreover, Van Kesteren et al. [13] suggested basic materials selection activities as follow: formulating material criteria, making a set of candidate materials, comparing candidate materials and choosing candidate material.

I.IV. MATERIAL SELECTION MODELS

The objectives of performance, cost and environmental sensitivity drive engineering design, and are generally limited by materials. Selection of the materials that best meet the requirements of the design and give maximum performance and minimum cost is the goal of optimum product design as Buggy approach[14]. However, some conflicting situations are generally observed between these objectives and criteria (i.e. young modulus/cost, or toughness/hardness) and there is a necessity to decide which property is more important than others. Using simple and logical methods, the criteria that influence material selection for a given engineering application must be identified to eliminate unsuitable alternatives and to select the most appropriate one according to Chatterjee and Edwards [15,16].

In order to solve the material selection issue of engineering components and to increase the efficiency in design process, many materials selection methods have been developed such as Ashby approach [17,18], TOPSIS (Technique for Order Performance by Similarity to Ideal Solution) [19,20,21,22,23], VIKOR, which means Multi-criteria Optimization and Compromise Solution) [24-27], ELECTRE stands for: (ELimination Et Choix Traduisant la REalité) which means (ELimination and Choice Expressing the REality), [28-30], PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) [15], COPRAS (complex proportional assessment) [31,32] and COPRAS-G [33] , graph theory and matrix approach [34], preference selection index (PSI) method [35] and linear assignment method [36].

A variety of quantitative selection methods have been developed to analyse the material selection process, thus a systematic evaluation for these methods is performed by A. Jahan, et. Al. [37]. The study seeks to address the following questions: (1): What is the contribution of the literature in the field of screening and choosing the materials?, (2) What are the methodologies, systems, tools for material selection of engineering components?. (3) Which approaches were prevalently applied?. (4) Is there any inadequacy of the approaches?. Interested reader could find many methods and analysis in this study.
TOPSIS method takes attention of many researchers in the field of material selection. Sharma et al. [38] proposed an expert system based on (TOPSIS) for aid in material selection process. Jee and Kang [22] introduced hybrid of Entropy and TOPSIS as tool in computer aided engineering (CAE) to help design engineers for material selection. As an example, the procedure of optimal material selection for a flywheel has been developed in their work. Milani [24] applied Entropy and TOPSIS in gear material selection and studied on effect of normalization norms on ranking of materials. Shanian and Savadogo [19] showed application of TOPSIS as a MADM method for solving the material selection problem of metallic bipolar plates for polymer electrolyte fuel cell. Since the Entropy method for deciding the relative importance of attributes does not give scope to designer's preferences, in their study a revised Entropy method was used for calculation of relative importance of each criterion. They also compared ordinary TOPSIS method to a modified version and showed efficiency of proposed method. Huang et al. [39] used the possible solutions search algorithm (PSSA) to pre-select the materials to obtain the feasible solutions, and applied TOPSIS method to acquire the optimal solution. Rao and Davim [23] offered a decision-making framework model for material selection using a combined multiple attribute decision-making method. The procedure was based on a combined TOPSIS and AHP method. According to A. Jahan, et. al. [37], the most popular approach adopted in the literature of material evaluation and selection are TOPSIS, ELECTRE and AHP have been the most popular state of the art methods in material choosing. Chart method, Computer-aided materials selection and knowledge-based systems are the most prevalent approach in material screening. Fuzzy methods prevalently have been used either individually or with other methods such as Genetic Algorithm [40], Neural Nnetworks [41], KBS [42], improved compromise ranking method [28], Graph theory [34] and Fuzzy rating [43].

Critical analyse to the MCDM approaches and try is cited by A. Jahan, et. Al. [36]. The authors lists many advantages and drawbacks for screening material methods. Instead of analysing every single approach in material choosing methods, the main focus of the authors are due to TOPSIS, ELECTRE and AHP, which are the three most popular selection approaches after 2005.
They listed the following drawbacks for these main models:

- Although ELECTRE methods have good output, they have a number of limitations: As the number of alternatives increases, the amount of calculations increases quite rapidly and computational procedures are quite elaborate.

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- ELECTRE only determine the rank of each material and do not give numerical value for better understanding of differences between alternatives.
- AHP is a powerful and flexible decision making procedure to help one set priorities and make the best decision when both tangible and non-tangible aspects of a decision need to be considered, but it only can compare a very limited number of decision alternatives, which is usually not more than 15. When there are hundreds or thousands of option to be compared, the pair wise comparison manner provided by the traditional AHP is obviously infeasible.
- TOPSIS is a good choice for material selection because of following reasons:
  - It is useful for qualitative and quantitative data.
  - It is relatively easy and fast, with a systematic process.
  - The output can be a preferential ranking of the candidate materials
  - With a numerical value that provides a better understanding of differences and similarities among alternatives.
  - This is especially useful when dealing with a large number of alternatives and criteria; the methods are completely suitable for linking with computer databases dealing with material selection.

However, there are two major drawbacks for TOPSIS method. The first drawback is the operation of normalized decision matrix in which the normalized scale for each criterion is usually derived a narrow gap among the performed measures. That is, a narrow gap in the TOPSIS method is not good for ranking and cannot reflect the true dominance of alternatives. Another drawback is that we never considered the risk assessment for a decision maker in the TOPSIS method. According to risk propensity, it has been commonly observed that decision makers differ in that willingness to overestimate the probability of a gain or a loss, the risk attitudes for a decision maker is usually categorized as risk-seeking, risk-neutral, and risk-averse. Without considering risk propensity, the subjective propensity associated with different decision maker preference cannot be determined, Ruey-Chyn [44]

I.V. WORK OBJECTIVES

Although a good amount of research work has already been carried out by the past researchers on design concept and materials selection applications using different MCDM methods, there is still a need to employ a simple and systematic mathematical approach to guide the decision maker in taking an appropriate product and material decisions for a specific engineering application. Although several techniques have been combined or integrated with the classical TOPSIS, many other techniques have not been investigated. These techniques make the classical TOPSIS more representative and workable in handling practical and theoretical problems by providing necessary analysis for original data.

This paper aims to: 1) explodes the possibility to propose an integrated decision-making approach based on fuzzy linguistic variables and geometric mean method integrated with TOPSIS framework which can support product development and material selection process under uncertain environments. 2) Apple this model after verification to a real life problem of design concept evaluation and other for material selection process.

This paper is divided into six sections. The initial section is the introduction. Section two proposes Fuzzy (GMM) – TOPSIS integrated approach in detail. Section three introduces evaluation criteria. Section four presents verification examples and section five represent real life applications for practical cases study, where section six present conclusions about the results.

II. PROPOSED FUZZY (GMM) -TOPSIS INTEGRATED APPROACH

The proposed model integrated approach composed of Fuzzy (GMM) and TOPSIS methods consist of three basic stages. The first stage data gathering to structure the hierarchy, stage two deals with Fuzzy computation where the third stage is values determination of the final ranking using TOPSIS method.

II.I. THE FIRST STAGE: STRUCTURING THE HIERARCHY

This is the first stage; a problem is decomposed into a hierarchical structure that consists of an objective (i.e., overall goal of the decision making), the general criteria which impact the goal directly, sub-criteria (objectives), sub-sub-criteria (measures) etc.

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II.II. THE SECOND STAGE: COMPUTING THE WEIGHTS

In this stage, to determine the criteria weights, a team of experts formed pair wise comparison matrices for evaluating the criteria. Each expert of the team established individual evaluation. Computing the geometric mean of the values obtained from individual evaluations, a final pair wise comparison matrix on which there is a consensus is found. The weights of the critical success factors are calculated based on this final comparison matrixes according to Fuzzy linguistic variables shown in table1and equations.[45]

Table 1. The pair wise comparison of linguistic variables using fuzzy numbers

45	Definition of linguistic variables	Fuzzy number	User define
$\tilde{1}$	Similar importance (SI)	(L,M,U)	= (, 1 ,)
$\tilde{3}$	Moderate importance (MI)	(L,M,U)	= (, 3 ,)
$\tilde{5}$	Intense importance (II)	(L,M,U)	= (, 5 ,)
$\tilde{7}$	Demonstrated importance (DI)	(L,M,U)	= (, 7 ,)
$\tilde{9}$	Extreme importance (EI)	(L,M,U)	= (, 9 ,)
$\tilde{2},\tilde{4},\tilde{6},\tilde{8}$	Intermediate values	(L,M,U)	= (, ,)

Where: L is the lower limit, M is the medium limit, U is the upper limit.

The corresponding membership function can be depicted as shown in Figure 1.

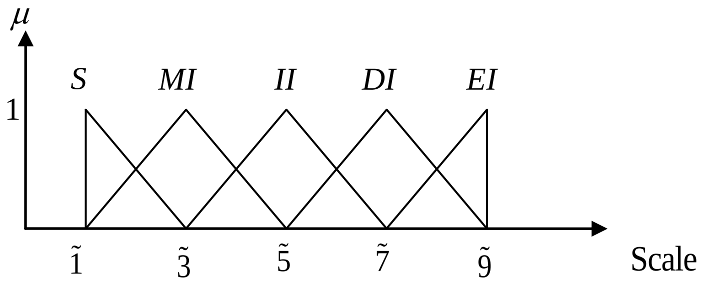

Fig 1. The membership function (μ) of linguistic variables

Next, from the information of the pair wise comparison, we can form the fuzzy positive reciprocal matrix as follows:

$$\tilde{\boldsymbol{A}} = \begin{bmatrix} \tilde{a}_{11} & \cdots & \tilde{a}_{1j} & \cdots & \tilde{a}_{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{a}_{i1} & \cdots & \tilde{a}_{ij} & \cdots & \tilde{a}_{in} \\ \vdots & & \vdots & & \vdots \\ \tilde{a}_{n1} & \cdots & \tilde{a}_{nj} & \cdots & \tilde{a}_{nn} \end{bmatrix} \qquad (1)$$

here $\tilde{a}_{ij} \square \tilde{a}_{ji} \approx 1$ and $\tilde{a}_{ij} \cong \frac{w_i}{w_j}$.

Then, the geometric mean method for finding the final fuzzy weights of each criterion can be formulated as follows:

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$$W_i = r_i * (r_1 + r_2 + \ldots\ldots\ldots\ldots r_n)^{-1}, \qquad (2)$$

where

$$r_i = (a_{i1} * a_{i2} * \ldots\ldots\ldots\ldots\ldots * a_{in})^{1/n}. \qquad (3)$$

After determining the weights for lower, median and upper comparison matrices, the weighting average is computed to get the final weights.[46]

II.III. THE THIRD STAGE :DETERMINING THE FINAL RANKING

In the last stage, calculated weights of the factors are approved by decision making team. Ranking firms are determined by using TOPSIS method in the This stage. In TOPSIS technique based on the concept that rank alternatives, which has the shortest distance from the ideal (Best) solution and the longest distance from the ideal (worst) solution.[47]

Steps of TOPSIS

Step 1: Construct normalized decision matrix. This step transforms various attribute dimensions into non-dimensional attributes, which allows comparisons across criteria.
Normalize scores or data as follows:

$$r_{ij} = x_{ij} / \sqrt{(\sum_{i=1}^{m} a^2_{ij})} \quad \text{for } i = 1, \ldots, m;\ j = 1, \ldots, n \qquad (4)$$

Step 2: Construct the weighted normalized decision matrix. Assume we have a set of weights for each criteria w_j for j = 1,…n. Multiply each column of the normalized decision matrix by its associated weight. An element of the new matrix is:

$$V_{ij} = w_j . r_{ij} = 1,2,3,\ldots., \quad j = 1,2,\ldots\ldots. \qquad (5)$$

Step 3: Determine the ideal and negative ideal solutions.
Ideal solution.

$$A^* = \{ v1^*, \ldots, vn^* \}, \text{ where}$$
$$V_j^* = \{ \max (V_{ij}) \text{ if } j \in J ;\ \min (V_{ij}) \text{ if } j \in J' \} \qquad (6)$$

Negative ideal solution.

$$A' = \{ V1', \ldots, V_n' \}, \text{ where}$$
$$V' = \{ \min (V_{ij}) \text{ if } j \in J ;\ \max (V_{ij}) \text{ if } j \in J' \} \qquad (7)$$

Step 4: Calculate the separation measures for each alternative. The separation from the ideal alternative is:

$$S_i^* = [\sum_{i=1}^{n} (Vij - Vj^*)^2]^{1/2} \qquad i = 1, \ldots, m \qquad (8)$$

Similarly, the separation from the negative ideal alternative is:

$$S'_i = [\sum_{i=1}^{n} (Vij - Vj')^2]^{1/2} \qquad i = 1, \ldots, m \qquad (9)$$

Step 5: the relative closeness of the alternative Ci* can be defined as

$$Ci^* = S'i / (Si^* + S'i), \qquad 0 < Ci^* < 1 \qquad (10)$$

Step 6: Select an alternative with maximum Ci* or alternative in the descending order based on the value of C_i^*.

Schematic diagram of the proposed model for best design is provided in Figure 2.

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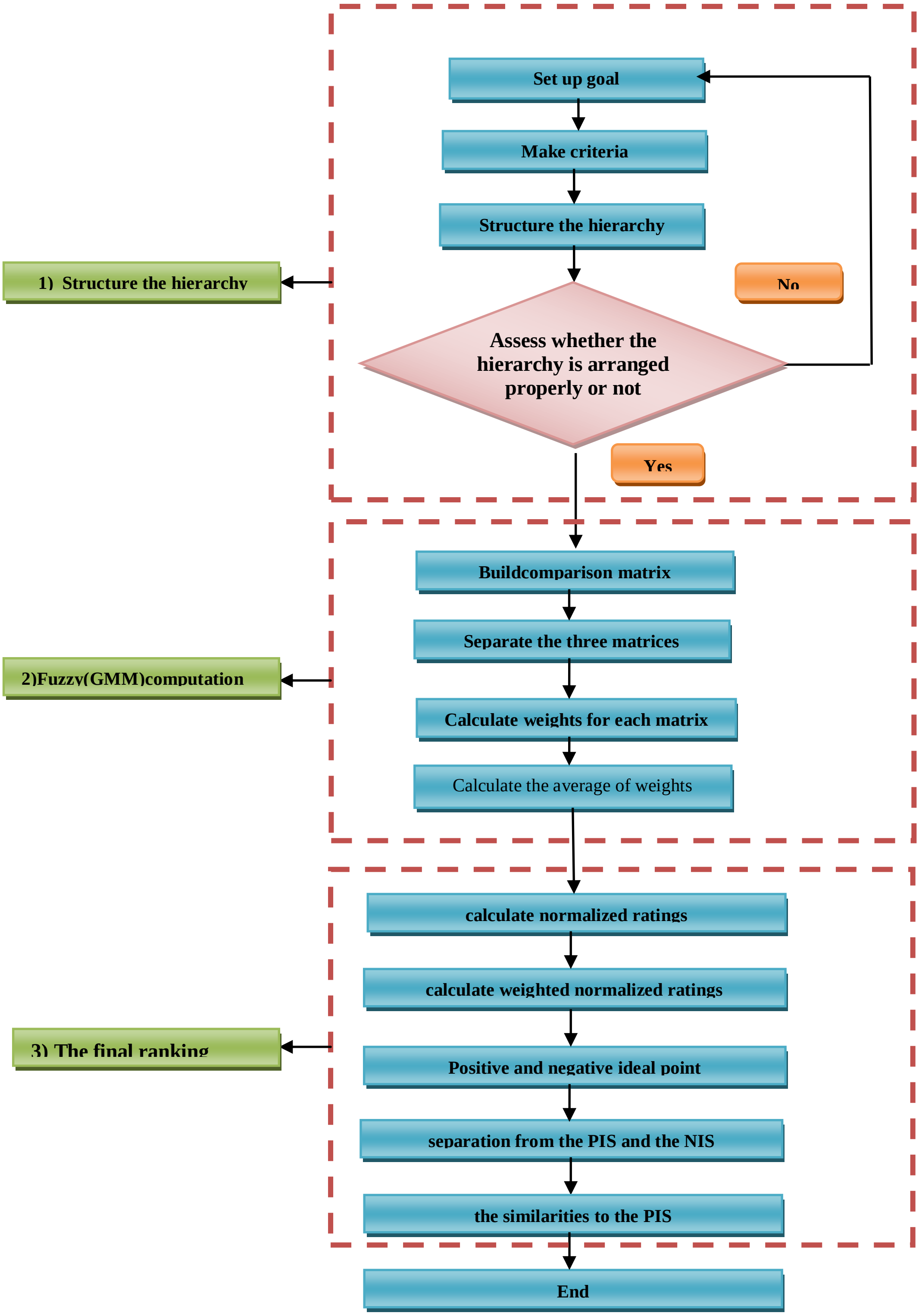

Fig 2. Schematic diagram for the Fuzzy (GMM) -TOPSIS integrated approach

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III. EVALUATION CRITERIA

Evaluation criteria are the tool needed to measure the performance of each prioritization methods. These criteria will compare and determine the best method among all the prioritization methods. In this study, Euclidean Distance (ED) and Approximation method is applied. For each particular comparison matrix in the hierarchy evaluation with aid of an error criteria ED will be performed. More precisely, the most appropriate method for each matrix can be selected by performing the multi criteria analysis of derived priority vectors across minimizing criteria ED.

III.I. EUCLIDEAN DISTANCE (ED)

ED is used to estimate the overall distance between all the judgment elements in the comparison matrix and associated ratios of the priorities from the derived vector weight. The best method is determined by the least ED value. The ED is measured in the following way:

$$ED = \left(\sum_{i=1}^{n}\sum_{j=1}^{n}\left(a_{ij} - w_i/w_j\right)^2\right)^{1/2} i,j = 1,2,\ldots\ldots..n. \qquad (11)$$

III.II. APPROXIMATION METHOD

The approximation method is used to calculate the minimum change of weights (changes= 0.001 in this paper) that can change the ranking of alternatives by using different ranking methods.

IV. VERIFICATION

Two decision problems are selected to illustrate the concept.

IV.I. EXAMPLE 1

In this example, a pair wise comparison matrix has been conducted based on data that are taken from Ying-Ming Wang et al. [48]. This example compares between different prioritization methods in terms of Euclidean distance (ED) as comparing criteria as shown in Figure 3. The results obtained from the Ying-Ming's study and the result using Fuzzy (GMM), are list in Table 2.

Apair wise comparison matrix

1	4	3	1	3	4
1/4	1	7	3	1/5	1
1/3	1/7	1	1/5	1/5	1/6
1	1/3	5	1	1	1/3
1/3	5	5	1	1	3
1/4	1	6	3	1/3	1

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Table 2. Priority vectors obtained by different priority methods .

Priority Method	Priorities (priorities or weights vector)					
	W1	W2	W3	W4	W5	W6
EVM	0.3208	0.1395	0.0348	0.1285	0.2374	0.1391
WLSM	0.4150	0.0936	0.0348	0.1123	0.2190	0.1253
LLSM	0.3160	0.1391	0.0360	0.1251	0.2360	0.1477
GLSM	0.3407	0.1205	0.0575	0.1495	0.2013	0.1305
GEM	0.3746	0.1722	0.0275	0.1252	0.2254	0.0751
FPM	0.3492	0.1438	0.0528	0.1232	0.1917	0.1392
CCMA	0.2768	0.1695	0.0295	0.1555	0.2072	0.1615
DEAHP	0.1875	0.1875	0.0625	0.1875	0.1875	0.1875
LP-GFW	0.4042	0.2130	0.0466	0.1793	0.3827	0.2056
AHP	0.3047	0.1486	0.0382	0.1414	0.2208	0.1463
Entropy	0.1002	0.2545	0.0619	0.1347	0.2356	0.2128
Fuzzy (GMM) TOPSIS	0.3114	0.1396	0.0367	0.1272	0.2362	0.1487

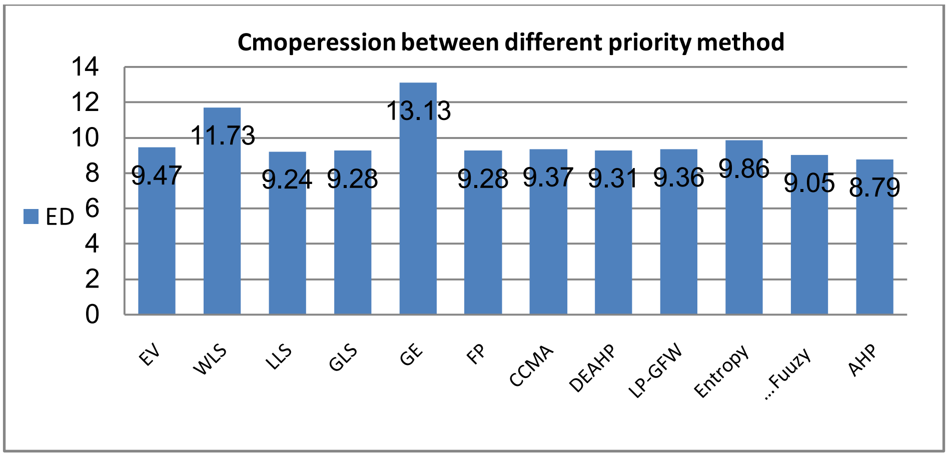

Fig 3. Compression between different priority methods

It is shown that, AHP method gives the least value of ED, but can not be relied upon in higher consistency. Fuzzy (GMM) prioritization model in case of high inconsistent matrices produces the second smaller or close to zero value of ED as comparing criteria (i.e. Fuzzy model is the best solution).

Agreement of MADM methods can be measured by the Spearman rank correlation which calculates the sums of the squares of the deviations between the different rankings. Table3represents Spearman's rank correlation coefficient between mentioned approaches. Fuzzy (TOPSIS) shows high Agreement with other methods.

Table 3. Spearman's rank correlation coefficient between MCDM methods .

	WLSM	GLSM	GEM	FPM	CCMA	DEAHP	LP-GFW	FUZZY (TOPSIS)
EVM	0.314	0.085	0.771	1	1	0.529	1	0.60
WLSM		0.771	0.771	0.314	0.314	0.755	0.314	0.828
GLSM			0.314	0.085	0.085	0.226	0.085	0.371
GEM				0.771	0.771	0.226	0.771	0.942
FPM					1	0.529	1	0.60
CCMA							0.529	0.30
LP-GFW								0.6

IV.II Example 2:

In this example, a case has been conducted based on data that are taken from Bojan's study [49]. The selected case is reservoir storage allocation problem. The analyzed problem is allocating the surface water reservoir storage to multiple uses. A global economical goal is defined as the most profitable use of reservoir, and six purposes are considered as decision alternatives: electric power generation (A1); irrigation (A2); flood protection (A3); water supply (A4); tourism and recreation (A5); and river traffic (A6). Alternatives are evaluated across five economical criteria of different metrics: gain in national income (C1); earning foreign exchange (C2); improvement of the balance of payment (C3); import substitution (self-sufficiency) (C4); and gain in regional income (C5). P1 is the matrix where criteria are compared by importance with respect to the goal, and matrices containing judgments of alternatives with respect to criteria C1, C2,…., C5 are referred to as P2,…., P6, respectively as shown in Table 4. The priority vectors for criteria is presented in table 5 and the Value of ED for all methods are presented in table 6 and comulative ED presented in Figure 4.

Table 4. Compression matrices for reservoir storage allocation problem .

Criteria (P1)					
	A1	A2	A3	A4	A5
A1	1	2	5	3	2
A2	1/2	1	7	3	3
A3	1/5	1/7	1	1/4	1/5
A4	1/3	1/3	4	1	3
A5	1/2	1/3	5	1/3	1

Balance of Payment (P4)						
	A1	A2	A3	A4	A5	A6
A1	1	3	7	6	3	4
A2	1/3	1	5	2	3	1/2
A3	1/7	1/5	1	1/4	1/7	1/3
A4	1/6	1/2	4	1	1/2	2
A5	1/3	1/3	7	2	1	2
A6	1/4	2	3	1/2	1/2	1

National Income(P2)						
	A1	A2	A3	A4	A5	A6
A1	1	5	3	6	7	5
A2	1/5	1	1/7	1/2	2	2
A3	1/3	7	1	7	3	4
A4	1/6	2	1/7	1	1/2	1
A5	1/7	1/2	1/3	2	1	2
A6	1/5	1/2	1/4	1	1/2	1

Import Substitution (P5)						
	A1	A2	A3	A4	A5	A6
A1	1	3	9	7	4	3
A2	1/3	1	3	6	2	1/3
A3	1/9	1/3	1	1/2	1/4	1/5
A4	1/7	1/6	2	1	1/6	1/6
A5	1/4	1/2	4	6	1	1/2
A6	1/3	3	5	6	2	1

Foreign Exchange(P3)						
	A1	A2	A3	A4	A5	A6
A1	1	4	6	7	2	2
A2	1/4	1	2	2	1	1/3
A3	1/6	1/2	1	2	1/6	1
A4	1/7	1/2	1/2	1	1/5	1/7
A5	1/2	1	6	5	1	1
A6	1/2	3	1	7	1	1

Regional Income (P6)						
	A1	A2	A3	A4	A5	A6
A1	1	1/5	1/3	1/6	1/3	1
A2	5	1	2	1/5	2	4
A3	3	1/2	1	1	2	3
A4	6	5	1	1	1	7
A5	3	1/2	1/2	1	1	5
A6	1	1/4	1/4	1/7	1/5	1

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Table 5. Priority vectors for criteria

Criteria	AN	EV	WLS	LLS	FPP	LGP	Entropy	Fuzzy (GMM)
	Priority Vectors							
C1	0.352	0.358	0.411	0.356	0.391	0.356	0.112	0.343
C2	0.3	0.306	0.291	0.313	0.283	0.356	0.307	0.317
C3	0.043	0.041	0.047	0.042	0.065	0.051	0.1	0.043
C4	0.172	0.171	0.14	0.166	0.152	0.119	0.297	0.168
C5	0.133	0.123	0.111	0.122	0.109	0.119	0.184	0.126

Table 6. Value of ED for all methods.

Method	P1	P2	P3	P4	P5	P6
	TD					
AN	4.583	6.209	5.305	6.797	6.107	4.786
EV	4.961	6.255	5.359	7.382	6.451	5.055
WLS	5.508	6.937	5.204	7.114	7.054	5.331
LLS	4.813	6.119	5.289	7.327	6.627	4.642
FPP	5.440	8.027	6.904	7.318	6.634	8.740
LGP	4.550	8.227	5.607	7.005	7.643	8.162
Entropy	8.573	13.298	12.991	10.146	13.705	11.11
Fuzzy (GMM) TOPSIS	4.504	5.907	5.350	6.930	6.270	4.590

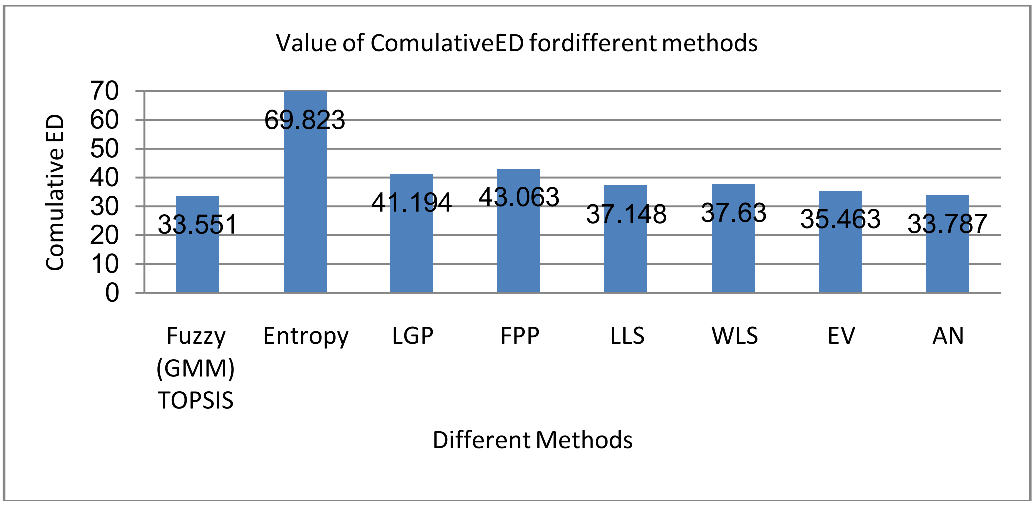

Fig 4. Value of ED for different methods

The results of this case, reservoir storage allocation problem table 6 and Figure 4 shows that, Fuzzy (GMM), AN (AHP) prioritization methods produce the smaller or close to zero the value of ED respictivily in comulative and individual (as comparing criteria i.e. P1, P2… and P6). Entropy weighting method produce the highest value.

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V. Cases Study

In the previous section verification of the model is presented. In this section two real life applications will be cited to demonstrate the applicability, simplicity and accuracy of the integrated model. These two applications have already been solved by the past researches and different ranking of the alternatives have been obtained. The first case is cited by H. Ariff, et. al. [10]. This case is about the selection of the best design concept for chair wheel transfer product. The second case is addressed by Ali Jahan et. al.[50] which is the selection of the most suitable material for the design of a flywheel.

V.I Problem1:

This proposed model is applied to a real problem in the industry. Inaccurate decision during the design stage can cause the product to be redesign or remanufactured. A study has been conducted based on data that are taken from case study used by H. Ariff, M. Sapuan, N. Ismail and Y. Nukman.[10]. This study is about wheelchair transfer problems. There are seven wheelchair design concepts of wheelchairs.. The main criteria affecting the development of wheelchair design are classified into five aspects; performance (P), safety (S), cost (C), ergonomic (E) and maintenance (M). There are five sub-criteria affecting the wheelchair performance: easy to transfer (ETT), easy to use (ETU), easy to storage (ETS), lightweight (LW) and strong framework (SF). Stability (ST) and no sharp edge (NSE) are sub-criteria that affect in terms of safety. While cost of material (CM) and cost of manufacturing process (CMP), easy to repair (ETR) and easy to dismantle (ETD), are sub-criteria affecting in terms of cost and maintenance respectively, show (Figure 3). This example is divided into three sections. Section one presented stages of the Fuzzy (GMM) -TOPSIS model. Section two presented comparison between results obtained by AHP and Fuzzy (GMM) -TOPSIS model by using Euclidean distance. Section three compares between three different ranking methods SAW, TOPSIS and VIKOR in terms of methods sensitivity of changing the weights. In this case, three scenarios are used equal weight, weight from AHP and GMM weight.

Section 1

- **The first stage is Structuring the hierarchy.**

In this section, a hierarchy model for structuring design concept decisions is introduced. A four level hierarchy decision process displayed in Figure 5 is described below:

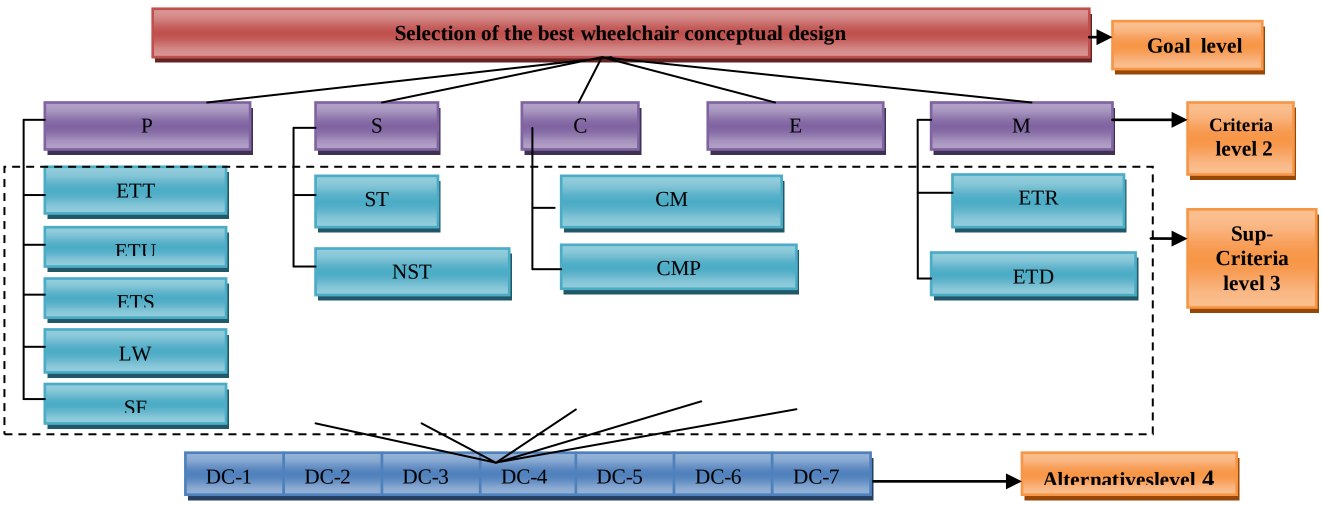

Fig 5. A hierarchy model for the selection of design concept

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Initially, the objective or the overall goal of the decision is presented at the top level of the hierarchy. Specifically, the overall goal of this application is to 'select the most suitable wheelchair conceptual design'. The second level represents the main criteria affecting the development of wheelchair design. The main criteria can be classified into five aspects: performance (P), safety (S), cost (C), ergonomic (E) and maintenance (M).The sub-criteria is represented at the third level of the hierarchy. There are five sub-criteria affecting the wheelchair performance: easy to transfer (ETT), easy to use (ETU), easy to storage (ETS), lightweight (LW) and strong framework (SF). Stability (ST) and no sharp edge (NSE) are sub-criteria that affect in terms of safety. While cost of material (CM) and cost of manufacturing process (CMP), easy to repair (ETR) and easy to dismantle (ETD), are sub-criteria affecting in terms of cost and maintenance respectively. Finally, at the lowest level of the hierarchy, the design concept (DC) alternatives of the wheelchair development are identified.

- **The second stage is computing the weights by Fuzzy (GMM)**

1- Pair wise comparison matrix

The pair-wise comparisons generate a matrix of relative rankings for each level of the hierarchy. The number of matrices depends on the number of elements at each level. The order of the matrix at each level depends on the number of elements at the lower level that it links to.
Pair-wise comparison begins with comparing the relative importance of two selected items. There are n × (n –1) judgments required to develop the set of matrices in this step. The decision makers have to compare or judge each element by using the relative scale pair wise comparison as shown in Table 1. Judgments are decided based on the decision makers or users experience and knowledge. The scale used for comparisons in Fuzzy (GMM) enables the decision maker to incorporate experience and knowledge intuitively. To do pair wise comparison, for instance as shown in Table 7, if performance (P) is strongly more important or essential over cost (C), then a = 5. Reciprocals are automatically assigned to each pair-wise comparison.

Table 7. Construct a Pair-wise Comparison Matrix

Goal	P	S	C	E	M
Performance (P)	[1,1,1]	[2,3,4]	[4,a,6]	[2,3,4]	[4,5,6]
Safety (S)	[1/4,1/3,1/2]	[1,1,1]	[2,3,4]	[1,1,1]	[2,3,4]
Cost (C)	[1/6,1/5,1/4]	[1/4,1/3,1/2]	[1,1,1]	[1/4,1/3,1/2]	[2,3,4]
Ergonomic (E)	[1/4,1/3,1/2]	[1,1,1]	[2,3,4]	[1,1,1]	[2,3,4]
Maintenance (M)	[1/6,1/5,1/4]	[1/4,1/3,1/2]	[1/4,1/3,1/2]	[1/4,1/3,1/2]	[1,1,1]

2- Separation

In this step, three matrices (Lower, Medium, Upper) are separated from the original matrix. The priority is calculated for each matrix separately.

3- Synthesizing the Pair wise Comparison

Normalized vector is computed according to eq.(3), where a_{ij} the element with i raw and j column. To calculate the vectors of priorities, sum the each element in the normalizing column. Then, divide the elements of each column by the sum of the column as shown in eq. (2). The result is priority vector as shown in table 8. This process is done on all three matrices (Lower, Medium, and Upper).

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Table 8. Synthesizing the Pair wise Comparison

Goal	P	S	C	E	M		Priority
(P)	1	2	4	2	4	2.297	0.453
(S)	1/4	1	2	1	2	1	0.197
(C)	1/6	1/4	1	1/4	2	0.461	0.091
(E)	1/4	1	2	1	2	1	0.197
(M)	1/6	1/4	1/4	1/4	1	0.304	0.060
Sum						5.062	

4- Calculate the final weights:

After calculate the priority victor for the three matrices (Lower, Medium, Upper) then calculate the average of each element in row of priority victor in three matrices as shown in table 9.

Table 9. The weights obtained from Fuzzy (GMM) of main criteria:

Weights	1	2	3	Average
w1	0.453	0.461	0.453	0.456
w2	0.197	0.194	0.192	0.195
w3	0.091	0.090	0.096	0.092
w4	0.197	0.194	0.192	0.195
w5	0.060	0.058	0.063	0.061

This process are repeated for all levels of hierarchy structure (criteria, sub-criteria and alternatives).
The priority vectors for criteria, sub-criteria and alternatives are represented in table 10. The overall priority vector can be obtained by multiplying the priority vector for the design alternatives by the vector of priority of the sub-criteria as shown in table 11.

Table 10. Represent priority vectors for criteria, sub-criteria and alternatives.

	GOAL											
	0.456					0.195		0.0928		0.195	0.061	
Criteria	P					S		C		E	M	
	0.451	0.265	0.060	0.140	0.082	0.750	0.261	0.750	0.2612	1	0.750	0.261
Sub-criteria	ETT	ETU	ETS	LW	SF	ST	NSE	CM	CMP	E	ETR	ETD
Alternatives												
DC-1	0.175	0.215	0.093	0.170	0.112	0.144	0.189	0.126	0.124	0.120	0.262	0.195
DC-2	0.104	0.081	0.074	0.290	0.061	0.055	0.058	0.229	0.227	0.066	0.191	0.316
DC-3	0.140	0.145	0.066	0.140	0.118	0.092	0.174	0.126	0.124	0.120	0.144	0.125
DC-4	0.126	0.044	0.070	0.127	0.061	0.062	0.055	0.229	0.227	0.050	0.093	0.101
DC-5	0.323	0.201	0.420	0.050	0.311	0.269	0.174	0.051	0.047	0.322	0.045	0.034
DC-6	0.080	0.162	0.074	0.167	0.084	0.147	0.174	0.169	0.182	0.100	0.098	0.165
DC-7	0.051	0.152	0.204	0.056	0.253	0.230	0.174	0.072	0.070	0.223	0.068	0.065

Table 11. Overall weight vector for the alternatives with respect to the criteria

ETT	ETU	ETS	LW	SF	ST	NSE	CM	CMP	E	ETR	ETD
0.206	0.121	0.027	0.064	0.038	0.146	0.051	0.070	0.024	0.195	0.046	0.016

- **Third stage : ranking alternatives by using TOPSIS method**

1- Construct normalized decision matrix

This step transforms various attribute dimensions into non-dimensional attributes, by using the eq. (4). To calculate the normalizing decision matrix, squaring each element of the matrix of alternatives. Then, sum the squaring elements in each column. After that, calculate the root for the sum in each column. Divide the elements in alternatives matrix of each column by the root in each column and the resulted normalized matrix stated in table12.

Table 12. Normalized decision matrix.

	ETT	ETU	ETS	LW	SF	ST	NSE	CM	CMP	E	ETR	ETD
DC-1	0.401	0.528	0.187	0.398	0.249	0.337	0.468	0.303	0.297	0.269	0.675	0.440
DC-2	0.238	0.199	0.149	0.679	0.136	0.129	0.144	0.551	0.544	0.148	0.492	0.713
DC-3	0.321	0.356	0.133	0.328	0.263	0.215	0.431	0.303	0.297	0.269	0.371	0.282
DC-4	0.289	0.108	0.141	0.297	0.136	0.145	0.136	0.551	0.544	0.112	0.240	0.228
DC-5	0.741	0.494	0.845	0.117	0.692	0.629	0.431	0.123	0.113	0.722	0.116	0.077
DC-6	0.183	0.398	0.149	0.391	0.187	0.344	0.431	0.406	0.436	0.224	0.252	0.372
DC-7	0.117	0.374	0.411	0.131	0.563	0.538	0.431	0.173	0.168	0.500	0.175	0.147

2- Construct the weighted normalized decision matrix by using eq. (5). In this step multiply each column of the normalized decision matrix by its associated weight in table 11 as shown in table 13.

Table 13. The weighted normalized decision matrix

	ETT	ETU	ETS	LW	SF	ST	NSE	CM	CMP	E	ETR	ETD
DC-1	0.0827	0.0639	0.0051	0.0255	0.0095	0.0492	0.0239	0.0212	0.0071	0.0524	0.0310	0.0070
DC-2	0.0491	0.0241	0.0040	0.0435	0.0052	0.0188	0.0073	0.0385	0.0131	0.0288	0.0226	0.0114
DC-3	0.0661	0.0431	0.0036	0.0210	0.0100	0.0314	0.0220	0.0212	0.0071	0.0524	0.0171	0.0045
DC-4	0.0595	0.0131	0.0038	0.0190	0.0052	0.0212	0.0069	0.0385	0.0131	0.0219	0.0110	0.0036
DC-5	0.1525	0.0598	0.0228	0.0075	0.0263	0.0918	0.0220	0.0086	0.0027	0.1407	0.0053	0.0012
DC-6	0.0378	0.0482	0.0040	0.0250	0.0071	0.0502	0.0220	0.0284	0.0105	0.0437	0.0116	0.0060
DC-7	0.0241	0.0452	0.0111	0.0084	0.0214	0.0785	0.0220	0.0121	0.0040	0.0975	0.0081	0.0023

3- Determine the ideal and negative ideal solutions.

Ideal solution is calculated by using the eq. (6). It is the maximum of performance and safety and minimum in cost. Negative ideal solution is calculated by using the eq. (7) and it is reverse to the Ideal solution. The ideal and negative ideal solution are presented in table 14.

Table 14. Ideal and negative ideal solutions

V+	0.1525	0.0639	0.0228	0.0435	0.0263	0.0918	0.0239	0.0086	0.0027	0.1407	0.0310	0.0114
V'	0.0241	0.0131	0.0036	0.0075	0.0052	0.0188	0.0069	0.0385	0.0131	0.0219	0.0053	0.0012

4- Calculate the separation measures for each alternative.

Separation from the ideal alternative is calculated using eq. (8). In this stage, each element in column in the weighted normalized decision matrix is subtracted from each element in column of ideal solution as show in table 15. After that, sum each element in the row of separation matrix. Calculate the root of the sum for each element in matrix to find the

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final separation. By the same manor calculate the separation from the negative ideal alternative by using eq. (9) and the result is show in table 16.

Table 15. The separation from the ideal alternative

	ETT	ETU	ETS	LW	SF	ST	NSE	CM	CMP	E	ETR	ETD
DC-1	0.0049	0.0000	0.0003	0.0003	0.0003	0.0018	0.0000	0.0002	0.0000	0.0078	0.0000	0.0000
DC-2	0.0107	0.0016	0.0004	0.0000	0.0004	0.0053	0.0003	0.0009	0.0001	0.0125	0.0001	0.0000
DC-3	0.0075	0.0004	0.0004	0.0005	0.0003	0.0037	0.0000	0.0002	0.0000	0.0078	0.0002	0.0000
DC-4	0.0087	0.0026	0.0004	0.0006	0.0004	0.0050	0.0003	0.0009	0.0001	0.0141	0.0004	0.0001
DC-5	0.0000	0.0000	0.0000	0.0013	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0007	0.0001
DC-6	0.0132	0.0002	0.0004	0.0003	0.0004	0.0017	0.0000	0.0004	0.0001	0.0094	0.0004	0.0000
DC-7	0.0165	0.0004	0.0001	0.0012	0.0000	0.0002	0.0000	0.0000	0.0000	0.0019	0.0005	0.0001

Table 16. The separation from the negative ideal alternative..

	ETT	ETU	ETS	LW	SF	ST	NSE	CM	CMP	E	ETR	ETD
DC-1	0.0006	0.0012	0.0000	0.0005	0.0001	0.0003	0.0008	0.0004	0.0004	0.0002	0.0022	0.0009
DC-2	0.0001	0.0001	0.0000	0.0022	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0010	0.0028
DC-3	0.0003	0.0004	0.0000	0.0003	0.0001	0.0001	0.0006	0.0004	0.0004	0.0002	0.0004	0.0003
DC-4	0.0002	0.0000	0.0000	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0001	0.0002
DC-5	0.0027	0.0010	0.0035	0.0000	0.0021	0.0017	0.0006	0.0013	0.0013	0.0026	0.0000	0.0000
DC-6	0.0000	0.0006	0.0000	0.0005	0.0000	0.0003	0.0006	0.0001	0.0001	0.0001	0.0001	0.0006
DC-7	0.0000	0.0005	0.0005	0.0000	0.0013	0.0012	0.0006	0.0010	0.0010	0.0010	0.0000	0.0000

5- The relative closeness to the ideal solution is calculated by using eq.(10). In this step each element in row of separation from the negative ideal alternative divides by the sum of separation ideal and negative ideal alternative. Then, the final rank is presented in table17.

Table 17. Result of selection

Ranking	Fuzzy (GMM) -TOPSIS	AHP
1	DC-5	DC-5
2	DC-1	DC-1
3	DC-7	DC-7
4	DC-3	DC-6
5	DC-6	DC-3
6	DC-2	DC-2
7	DC-4	DC-4

Section 2: **Comparison between priority methods**

In this section are presented a comparison between the results of weights vector by Fuzzy (GMM) , AHP and Entropy as shown in table 18. The comparison between different priority methods are presented in Figure 6.

Table18. Compression between different weighting method

Criteria	P	S	C	E	M
AHP	0.456	0.191	0.099	0.191	0.061
Fuzzy (GMM) –TOPSIS	0.456	0.195	0.092	0.195	0.061
Entropy	0.1779	0.2675	0.2079	0.2675	0.0793

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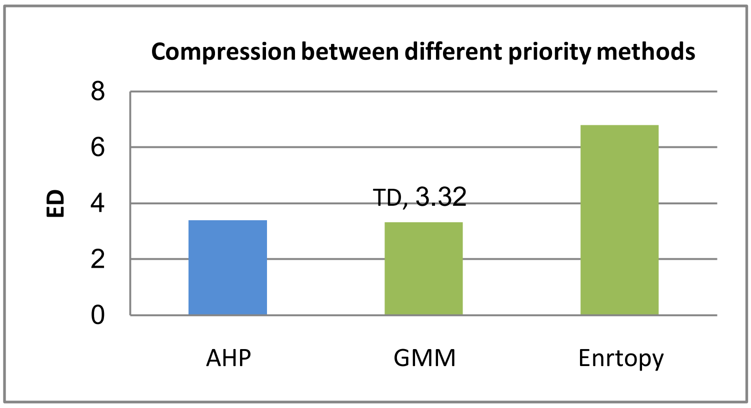

Fig 6. Compression between different priority methods

The results of this case, shows that, Fuzzy (GMM)- TOPSIS produce the smaller value of ED.

Section 3: Comparison between ranking methods

This section is a comparison between three different ranking methods SAW, TOPSIS and VIKOR in terms of methods sensitivity of changing the weights. Three scenarios are used for assigning importance (weight) to attributes.
Scenario a) Assume that equal weights are assigned to attributes which implies their equal importance to the decision maker.
Scenario b) Use the weights generated from the AHP as shown in table 19.

Table 19. The weights generated from the AHP

ETT	ETU	ETS	LW	SF	ST	NSE	CM	CMP	E	ETR	ETD
0.189	0.114	0.026	0.058	0.069	0.143	0.048	0.074	0.025	0.191	0.047	0.016

Scenario c) Use the weights generated from the Fuzzy (GMM) as shown in table 11. The results of scenario (a),(b),(c) are presented in table 20.

Table 20. Comparing between deferent ranking methods in deferent scenario

Ranking	Equal Weights			Weights by AHP			Weights by Fuzzy (GMM)		
	SAW	TOPSIS	VIKOR	SAW	TOPSIS	VIKOR	SAW	TOPSIS	VIKOR
1	DC-5	DC-5	DC-1	DC-5	DC-5	DC-5	DC-5	DC-5	DC-5
2	DC-1	DC-1	DC-5	DC-1	DC-7	DC-1	DC-1	DC-1	DC-1
3	DC-2	DC-7	DC-6	DC-7	DC-1	DC-3	DC-7	DC-7	DC-3
4	DC-6	DC-2	DC-7	DC-6	DC-3	DC-7	DC-6	DC-3	DC-7
5	DC-7	DC-3	DC-3	DC-3	DC-6	DC-6	DC-3	DC-6	DC-6
6	DC-3	DC-6	DC-2	DC-2	DC-2	DC-2	DC-2	DC-2	DC-2
7	DC-4	DC-4	DC-4	DC-4	DC-4	DC-4	DC-4	DC-4	DC-4

Table20, while ranking other alternatives, the SAW and VIKOR methods produce more similar ranks across different scenarios than the TOPSIS method. Because the TOPSIS method has high sensitivity to the changes in methods for assigning weights to criteria, it's frequently used as a benchmarking method.

For the wheelchair selection problem, all of the SAW, TOPSIS and VIKOR methods in each scenario give the top rank to the same alternative (DC-5) except the VIKOR in scenario "a". Figure 7 shows there are small variations in the rankings obtained using SAW, TOPSIS and VIKOR methods.

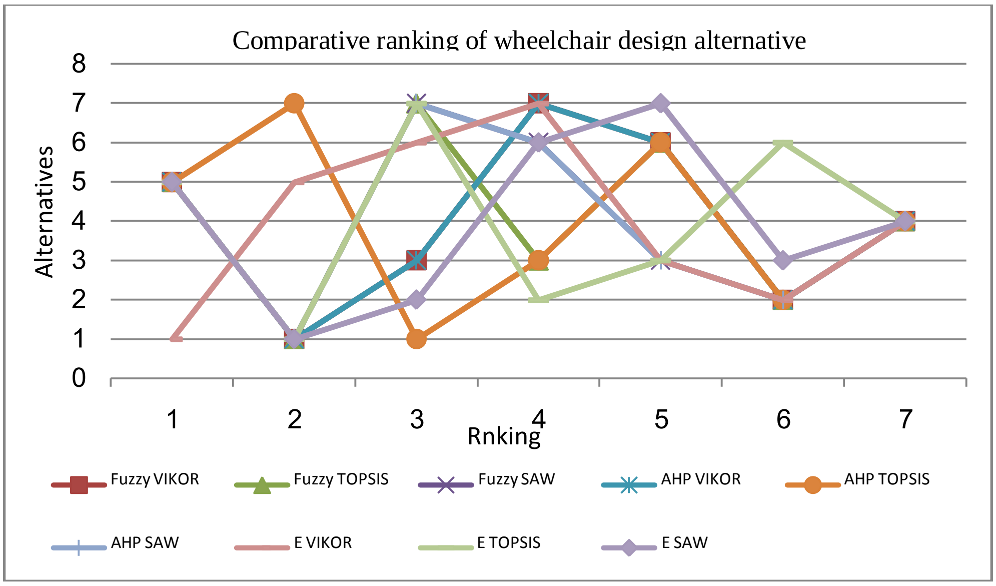

Fig. 7. Comparative ranking of wheelchair design alternative

Table 21 represents Spearman's rank correlation coefficient between mentioned approaches. High rank correlation between Fuzzy TOPSIS and Fuzzy SAW (0.678), Fuzzy TOPSIS and AHP VIKOR (0.428) and Fuzzy TOPSIS and (equal) TOPSIS (0.535) .

Table 21. Spearman's rank correlation coefficient between MCDM methods .

	Equal SOPSIS	Equal VIKOR	AHP SAW	AHP TOPSIS	AHP VIKOR	Fuzzy SAW	Fuzzy TOPSIS	Fuzzy VIKOR
E SAW	-0.178	-0.178	0.2	0.142	0.928	0.25	0.357	0.928
E TOPSIS		-0.32	0.428	-0.75	-0.178	0.428	0.535	-0.178
E VIKOR			0.392	-0.25	0.107	0.392	-0.035	0.107
AHP SAW				-0.60	0.535	1	0.678	0.535
AHP TOPSIS					0	-0.60	-0.285	0
AHP VIKOR						0.535	0.428	1
Fuzzy SAW							0.678	0.535
Fuzzy TOPSIS								0.428

This study uses an approximation method to calculate the minimum change of weights (changes= 0.001 in this study) that can change the ranking of alternatives by using different ranking methods TOPSIS, SAW, and VIKOR. The results are presented in table 22.This table explains how changes of weights contribute to the change of raking and also, shows that the TOPSIS method is more sensitive than others which changes its alternative's ranking by smallest change in weights of attributes.

Table 22. Sensitivity analysis for different methods.

TOPSIS						Changes= .003						
.Weights (W)	.206	.121	.027	.064	.038	.146	.051	.07	.024	.195	.046	.016
W changes	.210	.121	.031	.060	.042	.142	.051	.07	.024	.199	.050	.012
Results before changing (W)			Ranking			Results after changing (W)				ranking		
.814683			DC-5			.824263				DC-5		
.438619			DC-1			.434748				DC-7		
.427345			DC-7			.434599				DC-1		
.321119			DC-3			.318824				DC-3		
.269081			DC-6			.269222				DC-6		
.217484			DC-2			.209023				DC-2		
.171268			DC-4			.167655				DC-1		
SAW						Changes= .004						
.Weights (W)	.206	.121	.027	.064	.038	.146	.051	.07	.024	.195	.046	.016
W changes	.203	.121	.030	.067	.041	.149	.051	.07	.024	.198	.043	.013
Results before changing (W)			Ranking			Results after changing (W)				ranking		
.813289			DC-5			.820028				DC-5		
.59916			DC-1			.599075				DC-1		
.525928			DC-7			.527373				DC-7		
.477828			DC-6			.473117				DC-3		
.4732433			DC-3			.472852				DC-6		
.41713			DC-2			.410121				DC-2		
.339316			DC-4			.33575				DC-4		
VIKOR						Changes= .01						
.Weights (W)	.206	.121	.027	.064	.038	.146	.051	.07	.024	.195	.046	.016
W changes	.206	.111	.037	.054	.048	.156	.051	.08	.034	.185	.036	.006
Results before changing (W)			Ranking			Results after changing (W)				ranking		
0			DC-5			0				DC-5		
.502833			DC-1			.234395				DC-7		
.604242			DC-3			.510857				DC-1		
.739321			DC-7			.604738				DC-3		
.768263			DC-6			.781943				DC-6		
.859454			DC-2			.850231				DC-2		
.961268			DC-4			.930921				DC-4		

The last table explains how changes of weights contribute to the change of raking and also, shows that the TOPSIS method is more sensitive than others which changes its alternative's ranking by smallest change in weights of attributes.

V.II. Problem2:

This example has been conducted based on data that are taken from Ali Jahan et. al.[50]. This sace deals with the selection of the most suitable material for design of a flywheel which is a device to store kinetic energy as used in automobiles, urban subway trains, mass transit buses, wind-power generators, etc. The most important requirements in a flywheel design are to store the maximum amount of kinetic energy per unit mass and to ensure against premature failure due to fatigue or brittle fracture. The following characteristics are required for flywheel: (1) performance index of rlimit/q (where, rlimit is the fatigue limit of the material and q is the material density). This signifies that the higher the value of rlimit/q, the lower the weight of the material for a given fatigue strength and consequently, the kinetic energy per unit mass of the flywheel will be higher. (2) Fracture toughness (KIC) of the material will be the performance measure for failure due to brittle fracture. (3) The fragmentability of the flywheel material is an essential property from the safety point of view. If the flywheel breaks into small pieces at final failure, the hazard will be much reduced. (4) Price per unit mass. Among these four criteria, the beneficial attributes are fatigue limit, fracture toughness and fragmentability where higher values are desirable, and price/mass is a non-beneficial attribute where smaller value is always preferable. For more clarification in this example proposed method illustrated step by step.

The problem which consists of ten alternative materials and four material selection criteria are shown in Table 23. According to entropy method, [51] the weights of the considered criteria are as follow: wa = 0.4, wb = 0.3, wc = 0.2 and wd = 0.1.

Table23. Candidate materials for a flywheel

No.	Material	Fatigue (+)	Toughness (+)	Fragment ability (+)	Price (-)
1	300M	100	8	3	4200
2	2024T3	49	13	3	2100
3	7050T73561	78	12	3	2100
4	Ti6AL4V	108	26	3	10500
5	E glass epoxy FRP	70	10	9	2735
6	S glass epoxy FRP	165	25	9	4095
7	Carbon epoxy FRP	440	22	7	35470
8	Kevlar 29 epoxy FRP	242	28	7	11000
9	Kevlar 29 epoxy FRP	616	34	7	25000
10	Boron epoxy FRP	500	23	5	3150000

The result of ranking materials for different methods are shown in table 24. It is shown that all methods rank material number 9 (Kevlar 49-epoxy FRP) is the first which has the highest value (.93104). material number 7 (Carbon epoxy FRP) has the second value (.6884), thus we put 7 in rank 2 of column”a”as the same ranking of column "c" and "d" where column "b" rank material number 8 (Kevlar 29 epoxy FRP) in the second and column "e" rank material number 10 (Boron epoxy FRP).In the same way the material 2 (2024T3) has the lowest value (.2835) in column ‘‘a” which agree with the ranking of column "d" and "e" where column "b" rank material number 10 (Boron epoxy FRP) in the last one and column "c" rank material number 1 (300M) also in the last one .

Table 24. Cumparing between defferent ranking method .

Ranking	TOPSIS	Jee and kang	ELECTER	VIKOR	Linear assignment
1	9	9	9	9	9
2	7	8	7	7	10
3	10	6	6	10	7
4	8	7	8	8	8
5	6	1	10	6	6
6	4	4	4	4	4
7	5	3	5	5	1
8	1	5	3	3	3
9	3	2	2	1	5
10	2	10	1	2	2

For the flywheel material selection problem, all of the TOPSIS, Jee and Kang, ELECTER, VIKOR and the linear assignment methods give the top rank to the same material (Kevlar 49–epoxy FRP). Figure 8 shows there are small variations in the rankings obtained using Jee and Kang, ELECTER, VIKOR and linear assignment methods.

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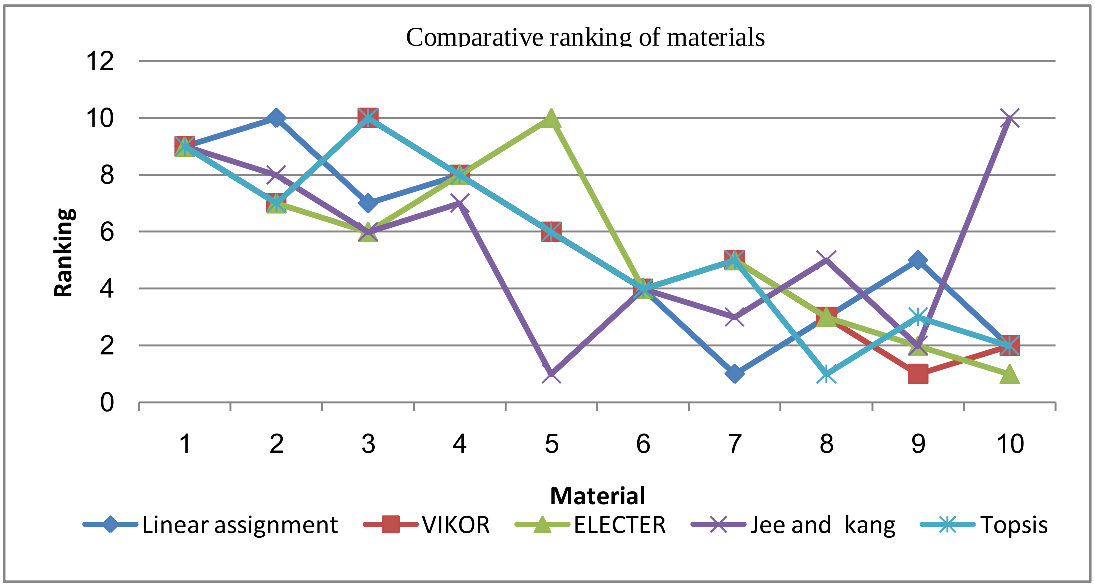

Fig. 8. Comparative ranking of materials

Agreement of MADM methods can be measured by the Spearman rank correlation which calculates the sums of the squares of the deviations between the different rankings. Table 25 represents Spearman's rank correlation coefficient between mentioned approaches. High rank correlation between TOPSIS and VIKOR (0.95), TOPSIS and linear assignment (.74) and TOPSIS and ELECTER (0.76) .

Table 25. Spearman's rank correlation coefficient between MCDM methods (Example 1).

	ELECTER	VIKOR	L. assignment	Topsis
Jee and Kang	-0.042	0.296	0.321	0.224
ELECTER		0.793	0.864	0.769
VIKOR			0.696	0.951
L. assignment				0.745

VI. Conclusion

In this paper, integrated Fuzzy (GMM –TOPSIS) decision making model have been developed. The model deals with both qualitative and quantitative criteria for best design concept and material selection process. The following conclusions could be summarized:

1- TOPSIS framework provides a perfect way to rank the candidate alternatives according to a decision matrix, while fuzzy-GMM is effective in conducting preliminary analysis of uncertainty in decision matrix.

2- GMM is used for computing weight which is an advanced step for TOPSIS to finding the final rank, fast, precise and easy.

3- From the numerical illustration for design concept evaluation of the wheelchair problem the analysis reveals that the design concept-5 is the most appropriate for further development because it has the highest value among the other design concepts. Application of Fuzzy-GMM TOPSIS model for selecting conceptual design at conceptual design stage can improve quality of product and shorten product development process.

4- Sensitivity analysis for the model provide that it has the smallest TD among other model and its sensitivity to change in alternative weighs is the best between all other (VIKOR, SAW) which mean more accurate result of priority.

5- The two cited examples demonstrate the potentiality, applicability and simplicity solving design concept and material selection decision-making problems and that the model is quite simple to implement involving a large reduction of mathematics as compared to the other conventional material selection methods.

6- The results derived using both this model show an excellent correlation with those obtained by the past researchers which specifically prove the global applicability of this method while solving such type of complex design or material selection problems.

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