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Capturing Design Intent During Concept Evaluation Using Rough Numbers and TODIM Method

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Abstract. Design concept evaluation is one of the critical stages of the early design process during which effective decision-making ensures the success of new product development (NPD). The information available to the designer during this stage is dynamic, incomplete, and qualitative. It is necessary to capture design intent during this stage to make the decision-making process effective. The main objective of this work is to reduce the uncertainty as well as subjectivity involved in the customers' preference evaluations and the decision-makers' judgments, thus, improving the effectiveness of the concept evaluation process. This paper proposes a novel way of performing design concept evaluations by capturing and considering the risk preferences of designers, instead of considering the cost and benefit characteristics of design criteria. The advantage of rough numbers in handling subjectivity and the merits of prospect theory in calculating the risk preferences are combined to propose an integrated approach known as Rough-TODIM for the design concept evaluation. The decisions of the designers are captured in the form of profit/advantage, loss/ setback, and no profit/no loss during decision-making. This profit/loss represents the design intent during the product development process.

Keywords: Product Design, Design Intent, New Product Development, Concept Evaluation, Decision Making, Rough Numbers.
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1 INTRODUCTION

Design concept evaluation is one of the most important phases of the early design process which influences the success of new product development (NPD). The main objective of this work is to reduce the subjectivity involved in the customers' preference evaluations and the decision-makers' judgments, thus, improving the effectiveness of the concept evaluation process. This paper proposes an alternate way of performing design concept evaluations by capturing and incorporating the risk preferences of designers, instead of considering the cost and benefit characteristics of design criteria. All the decisions, which a designer takes during the decision-making process are captured in the form of profit/advantage, loss/setback and no profit/no loss. This profit/loss depicts the design intent during the concept evaluation process. In this work, the advantage of rough numbers [21] in handling subjectivity and the merits of prospect theory [11] in considering risk preferences are combined to propose an integrated approach for the design concept evaluation. The work performs concept evaluations in two stages. In the first stage, the ranking of design criteria in terms of their relative importance is computed based on the importance assigned to each design criterion by the designers or the decision-makers (DM). In the second stage, customers' preferences for the generated user requirements are captured in the form of rough numbers [21]. The relative importance ranking computed in the first stage along with customers' preferences in the form of rough numbers are then used to develop rules for computing gain and loss to the designers during concept evaluation. In the second stage, these rules are incorporated into a framework of Interval-Valued fuzzy TODIM [13] (an acronym in Portuguese for iterative multi-criteria decision-making) using fuzzy numbers to select the best concept. Gomes and Lima [7] first proposed the TODIM method. The above framework is modified by using rough numbers instead of fuzzy numbers to propose a novel method known as Rough-TODIM.

The Rough TODIM method is primarily developed for capturing the design intent thus resulting in effective concept evaluation. The previously developed concept evaluation methods consider only customer requirements as a major parameter during the selection of the best concept. They do not incorporate the intent of designers or decisions which designers need to take to satisfy improperly defined customer requirements. Also, customer requirements and preferences are dynamic, the evaluated concept may not remain the best after some time. The designers' efforts to handle poor customer requirements as well as changing customer preferences are captured here in the form of gain or loss and rough numbers respectively. The proposed method thus incorporates both the intent of designers and customers to develop an effective concept evaluation method.

2 LITERATURE REVIEW

Design Concept evaluation is a multi-attribute decision-making (MADM) problem [6] that mainly involves two stages. The first stage consists of evaluating the design information like design criteria and their relative importance (weights) and the second stage involves combining the design information to evaluate the optimal/best design concept [15]. Concept evaluation involves decision-making in an uncertain environment which can be solved by using representative MADM methods [5] like the technique for order of preference by similarity to ideal solution (TOPSIS) [3], AHP [19], TOmada de Decisao Interativa Multicriterio (TODIM) [7].

Many researchers have used multi-criteria decision-making methods like the VIKOR method, TOPSIS, Analytic Hierarchy Process (AHP), Quality Function Deployment (QFD), etc. combined with many mathematical theories like grey theory, fuzzy theory, rough set theory and interval mathematics to develop effective concept evaluation methods. The vagueness involved with the judgements of the decision maker and the uncertainty of design information are the main reasons which encourage many researchers to use integrated fuzzy decision-making methods [9][10][12][24] in design concept evaluation. Ayag [2] proposed a hybrid approach utilizing both ANP and TOPSIS. ANP was used by Ayag for evaluating the weight of the criteria and TOPSIS was used to evaluate the ranking of the design alternatives.

In addition to fuzzy set theory, rough set theory and vague set theory were also used by many researchers in design concept evaluation [8]. Tiwari et al. [17] proposed an effective design concept evaluation method based on rough numbers and the VIKOR method. Zhang et al. [22] used vague sets in supplier selection problems. Zhu et al. [25] proposed an integrated concept evaluation method using AHP and VIKOR methods based on rough numbers. Shidpour et al. [14] combined a few concepts of fuzzy set theory, rough set theory and TOPSIS to develop a design concept evaluation framework. Rough numbers in combination with MCDM have been used by many researchers in design concept evaluations, but very few have captured useful information in the form of profit or loss to the designer during decision-making in the uncertain environment of early design stages. In most of the concept evaluation frameworks, the characteristics of design criteria in terms of cost and benefit are considered, but, in this paper, the importance characteristics of design criteria are used which helps the designer to reduce the uncertainty of decision-making. Table 1 represents the rough numbers based design concept evaluation methods, as reported in the literature.

Concept Evaluation Method	*Evaluation Method*	*Researchers*
Rough AHP-VIKOR	Rough numbers	Zhu et al [25]
Rough BWM-CRITIC-TOPSIS	Rough numbers	Song et al [16]
Fuzzy rough number AHP-TOPSIS	Fuzzy Rough Numbers	Zhu et al [24]
Interval rough integrated cloud-based TOPSIS	Integrated rough number	Xiao et al [18]
Rough-Z-number-enhanced MCGDM	Rough-Z-number	Zhu et al [23]

Table 1: Rough Numbers in Design Concept Evaluation Methods.

3 METHODOLOGY

The Rough-TODIM method involves two stages

1. Evaluation of weights and importance ranking of design criteria
2. Computing the ranking of design alternatives

In Stage 1, the evaluation of weights and importance ranking of the design criteria is determined by a method proposed by Tiwari et al. [17] and Zhai et al. [20]. These weights and importance rankings are then introduced in the proposed rough-TODIM method to evaluate the ranking of design alternatives. The ranking obtained by the rough-TODIM method captures both, i.e., the designers' judgments and the customers' preferences in the risk environment. Taking advantage of the rough numbers to capture the judgements of designers of the design criteria in terms of importance in Stage 1, Stage 2 uses this importance ranking of design criteria in the Interval-Valued TODIM [13] with a few modifications to compute the ranking of design concepts. The ranking calculated by the proposed method considers the psychological behavior of designers which makes this method more effective in comparison to previously proposed design concept evaluation methods.

3.1 Mathematical Model

The design criteria are determined by the designers based on user surveys and customer requirements. These design criteria have certain values which show the performance of the alternatives for that criteria. Let design concepts/alternatives be denoted by the layered vector set $A = \{A_1, A_2, \ldots, A_k, \ldots, A_n\}$, where each A_k be denoted by a layered vector set as $A_k = \{C_1, C_2, \ldots, C_k, \ldots, C_m\}$ where C_k represents the design criteria. The performance of an A_k for any C_k can be measured by the value of that design criteria. The weights of design criteria and importance ranking are calculated by following steps:

1. Identify the design criteria and design alternatives based on customer requirements.
2. Obtain the qualitative and quantitative judgements on each design criterion by potential designers.
3. Aggregate the judgements of all designers for each design criterion and convert them into rough numbers as proposed by Tiwari et al. [17]. Normalize the rough numbers to compute the weight of the design criteria.
4. Based on the value of the weights, the importance rating of the design criteria is calculated in terms of most important, important, average importance and low importance by the rules proposed by Zhai et al. [20].

In Stage 2, customer preferences for criteria values are captured in the form of rough numbers. These customers' preferences, criteria weights and importance ratings are used in the framework of Interval-Valued TODIM [13] along with rules developed for profit and loss to propose a novel model of concept evaluation, namely Rough-TODIM. The important step of this stage is as follows:

1. Obtain the qualitative and quantitative judgements on each design criterion value by customers.
2. Aggregate the judgements of all the customers for each design criterion value and convert them into rough numbers and normalize them as proposed by Tiwari et al. [17]. This will form the rough normalized decision matrix. The decision matrix is in the form of Table 2.
3. Calculate the dominance of each alternative A_i over A_j using Equation (1):

$$\delta(A_i, A_j) = \sum_{c=1}^{n} \varphi_c (A_i, A_j) \ \forall (i,j) \tag{1}$$

where the value of $\phi_c(A_i, A_j)$ as proposed by Krohling et al. [13] for the profit, loss and neutral condition for the designer are mentioned as $\sqrt{\frac{W_{rc}}{\sum_{c=1}^{m} W_{rc}}\left(d(A_i, A_j)\right)}$, $\frac{-1}{\theta}\sqrt{\frac{W_{rc}}{\sum_{c=1}^{m} W_{rc}}\left(d(A_i, A_j)\right)}$ and 0 respectively. The term $\varphi_c(A_i, A_j)$ represents the dominance contribution factor of criterion to the term $\delta(A_i, A_j)$. The term $\left(d(A_i, A_j)\right)$ stands for the distance between the performance values of alternatives (P_{ic}^-, P_{ic}^+) and (P_{jc}^-, P_{jc}^+). The W_{rc} is evaluated by dividing the weight of the criterion by the weight of the reference criterion. The term (P_{ic}^-, P_{ic}^+) denotes the lower and upper limit performance value of alternative A_i. It is calculated by Equation (2):

$$|P_{jc}^- - P_{ic}^-| + |P_{jc}^+ - P_{ic}^+| \tag{2}$$

Alternatives	*Criteria*			
	C_1	**C_2**	**C_3**	**C_4**
A_1	(P_{11}^-, P_{11}^+)	(P_{12}^-, P_{12}^+)	(P_{12}^-, P_{12}^+)	(P_{12}^-, P_{12}^+)

A_2	(P_{21}^-, P_{21}^+)	(P_{22}^-, P_{22}^+)	(P_{23}^-, P_{23}^+)	(P_{24}^-, P_{24}^+)
A_3	(P_{31}^-, P_{31}^+)	(P_{32}^-, P_{32}^+)	(P_{33}^-, P_{33}^+)	(P_{34}^-, P_{34}^+)
A_4	(P_{41}^-, P_{41}^+)	(P_{42}^-, P_{42}^+)	(P_{43}^-, P_{43}^+)	(P_{44}^-, P_{44}^+)

Table 2: Rough Normalized Decision Matrix.

The term θ represents the attenuation factor of the losses. Here, the risk preferences of the designers are incorporated in the framework of rough TODIM by proposing the condition for profit, loss, partial gain and partial loss to the designer during decision-making. The rules for calculating risk preferences for the designer are:

1. If the criterion is important or most important as well as customer preference is more for that alternative in comparison to the other alternatives then it is a gain/advantage for the designer, otherwise loss/setback to the designer.
2. If the criterion is averagely important, as well as customer preference is more for that alternative in comparison to the other alternatives, then it is partial profit to the designer, else partial loss. In such cases, a factor of 0.5 is multiplied to both the terms $\sqrt{\frac{W_{rc}}{\sum_{c=1}^{m} W_{rc}}}\left(d\left(A_i,A_j\right)\right)$, $\frac{-1}{\theta}\sqrt{\frac{W_{rc}}{\sum_{c=1}^{m} W_{rc}}}\left(d\left(A_i,A_j\right)\right)$ to compensate for the average important criteria.
3. If the criterion is less important as well as customer preference is low for that alternative in comparison to the other alternatives, then it is a loss to the designer, otherwise a profit.
4. The final dominance matrix is the sum of all dominance matrices for each criterion.
5. Normalize the final dominance matrix. Equation (3) represents the global value of any alternative A_i. The best alternative is to have the highest value of ε_i

$$\varepsilon_i = \frac{\sum\delta(i,j) - \min\sum\delta(i,j)}{\max\sum\delta(i,j) - \min\sum\delta(i,j)} \qquad (3)$$

The implementation process for both stages is shown in Figure 1 and Figure 2.

4 CASE STUDY: DESIGN CONCEPT EVALUATION OF WEIGHTLIFTING BENCH

In this manuscript, to demonstrate the application of the proposed method, a design illustration of a Weightlifting Bench is taken as a case study. The objective of the proposed concept evaluation method is to identify the best alternative in an uncertain (risk) environment by identifying the gain or losses to the designer during the decision-making. The best concept also satisfies the maximum preferences of customers as well. A total of four design concepts, namely, A_1, A_2, A_3, and A_4 are modeled and rendered in the CAD environment and shown in Figure 3. These alternatives are real-world examples taken from Amazon [1]. Customers can compare the performances of alternatives created by four design criteria which were identified by the designers based on customer surveys. These design criteria include the overall size of the bench, various important features of the bench related to safety and ergonomics, cost and weight of the bench, as well as the weight capacity of the bench. These criteria are identified by the designer based on the customer needs generated from the primary and secondary research. The criteria considered here are C_1 = Size of the bench, C_2 = Safety and Stability features, C_3 = Overall cost, and C_4 = Weight of the bench.

Customer requirements are represented with the help of the design criteria values, e.g., C_1 can be small, medium, large, very large; C_2: very less, less, Average, high; C_3: low, medium, high, very high; and C_4: low, medium, high, very high. Each design alternatives have one value from each design criterion which represents the performance of that concept. Table 3 represents the performance of each alternative.

Design Criteria	*Alternatives*			
	A_1	**A_2**	**A_3**	**A_4**
C_1	large	small	Very large	Medium
C_2	Very Less	Less	Average	High
C_3	Very High	Medium	High	Low
C_4	High	Medium	Very High	Low

Table 3: Performance of each alternative.

4.1 Computing the Weight and Ranking of Design Criteria

During this stage, to capture the subjective judgements of designers towards design criteria, symmetrical triangular fuzzy numbers (STFNs) are used. For capturing the perception of the designers, the 9-point scale proposed by Chakraborty [3] is used in this work. The scale is shown in Table 4. Four Designers (D1, D2, D3, D4) were asked to assign their importance rating for the design criteria generated using the scale shown in Table 5. STFNS can capture the vagueness of designers' judgements but evaluating the fuzzy membership is difficult in the case of STFNs [21]. Therefore, the STFNs ratings are then converted into rough numbers as suggested by Tiwari et al. [17]. The STFNs are converted into rough numbers for capturing the true perceptions of the designers as shown by an example class having elements as {7, 5, 3, 7}. The lower limit of the rough number is calculated by considering an average of all the elements which have class values equal to or less than C. The upper limit is calculated by considering an average of all the elements which have class values equal to greater than C. Here C is the STFN rating that is needed to be converted into rough numbers. The STFN 7 is converted into a rough number as [(7+7+5+3)/4, (7+7)/2], i.e., [5.5,7]. Individual judgements of design criteria in the form of rough numbers are depicted in Table 6. These individual judgements are then converted into combined judgements by taking the average of the ratings of design criteria by each designer. Combined judgements of the designers for each design criterion are shown in Table 6 along with normalized values which depict the weight of the design criteria. For evaluating the importance ranking of design criteria, the comparison rules proposed by Zhai et al. [21] are used. If $[L_1, U_1]$ and $[L_2, U_2]$ are two rough numbers and M_1, M_2 their median, the ranking rules can be described through Table 7a. The design criteria are compared based on rules proposed by Zhai et al. [21] and categorized as most important, important, medium important and less important, which are shown in Table 7b.

4.2 Computing the Ranking of the Alternatives

Table 3 is rearranged to develop a decision matrix as shown below. The decision matrix represents the performance of the design alternatives for each criterion which is termed here as criteria values.

$$\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array}\begin{array}{c} \begin{array}{cccc} \quad C_1 \quad & \quad C_2 \quad & \quad C_3 \quad & \quad C_4 \quad \end{array} \\ \begin{bmatrix} \text{High} & \text{Very low} & \text{Very High} & \text{High} \\ \text{Low} & \text{Low} & \text{Medium} & \text{Medium} \\ \text{Very High} & \text{Medium} & \text{High} & \text{Very High} \\ \text{Average} & \text{High} & \text{Low} & \text{Low} \end{bmatrix} \end{array}$$

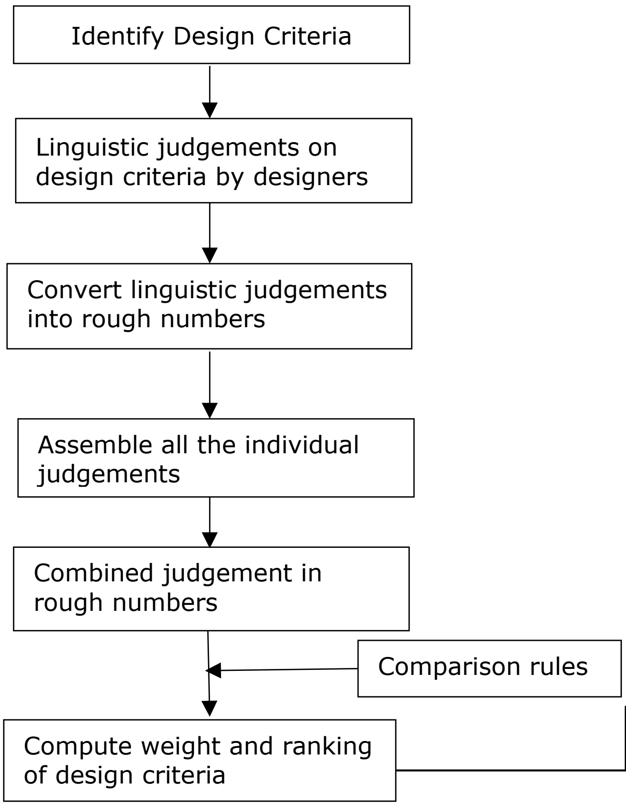

Figure 1: Implementation Steps of Stage 1.

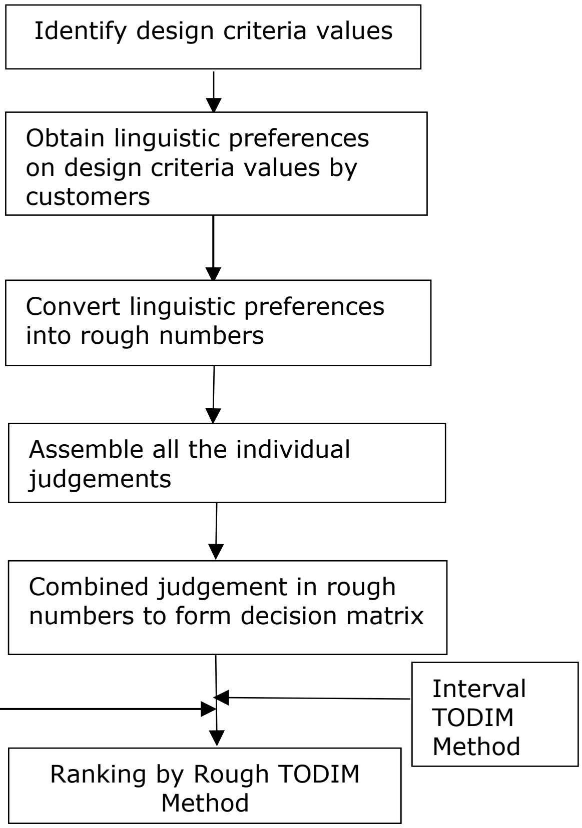

Figure 2: Implementation Steps of Stage 2.

Importance	*STFNs*
Very low	1 [0,2], 2 [1,3]
Low	3 [2,4], 4 [3,5]
Moderate	5 [4,6]
Moderate	6 [5,7]
High	7 [6,8]
High	8 [7,9]
Very High	9 [8,10]

Table 4: Scale Ratings.

Figure 3: Design alternatives taken from the real world referred from left to right a) A_1 b) A_2 c) A_3 d) A_4.

Design Criteria	*Ratings by the Designers*			
	D_1	**D_2**	**D_3**	**D_4**
C_1	7 [6,8]	5[4,6]	7[6,8]	3[2,4]
C_2	5[4,6]	5[4,6]	7[6,8]	7[6,8]
C_3	7[6,8]	3[2,4]	3[2,4]	7[6,8]
C_4	3[2,4]	3[2,4]	3[2,4]	5[4,6]

Table 5: Importance assigned to design criteria.

During the survey, the customer specifies their needs in linguistic form, which needs to be converted into quantifiable terms. In this work, the preferences of the customers for the criteria values are obtained by conducting a customer survey, where four customers are asked to assign their ratings {7 = high preference, 5 = medium preferences, 3 = low preference, 1 = very low preference} which are as follows:

Design Criteria	*Ratings converted into rough numbers*			
	D_1	**D_2**	**D_3**	**D_4**
C_1	[5.5, 7]	[4, 6.33]	[5.5, 7]	[3, 5.55]
C_2	[5,6]	[5,6]	[6,7]	[6,7]
C_3	[5,7]	[3,5]	[3,5]	[5,7]
C_4	[3,3.5]	[3,3.5]	[3,3.5]	[3.5,5]

Table 6: Importance assigned to design criteria in the form of rough numbers.

Comparison Condition	*Rule*
$U_1 > U_2$, $L_1 > L_2$	$RN_1 > RN_2$
$U_1 > U_2$, $L_2 > L_1$, $M_2 > M_1$	$RN_2 > RN_1$
$U_1 > U_2$, $L_2 > L_1$, $M_1 > M_2$	$RN_1 > RN_2$
$U_1 = U_2$, $L_1 = L_2$	$RN_1 = RN_2$

Table 7a: Comparison rules for evaluating the importance ranking of criteria.

Design Criteria	*Combined Judgement in rough numbers*	*Weight of design criteria*	W_{rc}	*Importance ranking of design criteria*
C_1	[4.5, 6.47]	[0.69, 0.99]	0.857143	Important
C_2	[5.5,6.5]	[0.84, 1]	1	Most Important
C_3	[4,6]	[0.61, 0.92]	0.666571	Medium
C_4	[3.125,3.875]	[0.48, 0.59]	0.333429	Low Important

Table 7b: Combined Judgement and weight of design criteria.

$$P_1=\begin{matrix} 7 & 5 & 1 & 7 \\ 5 & 7 & 7 & 1 \\ 3 & 3 & 5 & 5 \\ 1 & 1 & 3 & 3 \end{matrix} \quad P_2=\begin{matrix} 5 & 7 & 3 & 1 \\ 7 & 5 & 1 & 5 \\ 3 & 3 & 5 & 7 \\ 1 & 1 & 7 & 3 \end{matrix} \quad P_3=\begin{matrix} 5 & 7 & 1 & 3 \\ 7 & 5 & 3 & 1 \\ 3 & 3 & 5 & 7 \\ 1 & 1 & 7 & 5 \end{matrix} \quad P_4=\begin{matrix} 3 & 5 & 1 & 7 \\ 1 & 7 & 3 & 3 \\ 7 & 1 & 7 & 5 \\ 5 & 3 & 5 & 1 \end{matrix}$$

These preferences are then converted into rough numbers to develop a combined decision matrix as Equation (4):

$$A=\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array}\begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array} \\ \begin{bmatrix} [4.5, 5.83] & [5.5, 6.5] & [1.125, 1.875] & [3, 6.04] \\ [3.5, 6.33] & [5.5, 6.5] & [2.29, 4.79] & [1.54, 3.5] \\ [3.22, 4.75] & [2.125, 5.75] & [5.125, 5.875] & [5.5, 6.5] \\ [1.25, 2.75] & [1.125, 1.875] & [4.5, 4.70] & [2.165, 3.83] \end{bmatrix} \end{array} \quad (4)$$

This matrix is then normalized to develop a normalized decision matrix which is shown in Equation. (5). Calculating the dominance of each alternative A_i over A_j using Equation (1) which is shown in Table 8. The evaluation of dominance is done by considering the risk preferences of designers. These risk preferences are evaluated in terms of profit and loss which are defined in Section 3.1.

$$A=\begin{array}{c} \\ A_1 \\ A_2 \\ A_3 \\ A_4 \end{array}\begin{array}{c} \begin{array}{cccc} C_1 & C_2 & C_3 & C_4 \end{array} \\ \begin{bmatrix} [0.692, .896] & [0.846, 1] & [0.173, .288] & [0.461, .929] \\ [0.538, .973] & [0.846, 1] & [0.352, .736] & [0.236, .538] \\ [0.495, .730] & [0.326, .884] & [0.788, .903] & [0.846, 1] \\ [0.192, .423] & [0.173, .288] & [0.692, .723] & [0.333, .589] \end{bmatrix} \end{array} \quad (5)$$

The final (overall) dominance is the sum of all dominances for each alternative as shown in the third column of Table 7. The global measurements (calculated with Equation (3)) and the ranking of the alternatives are shown in Table 9. For $\theta = 1$, the ranking of the alternative is $A_2 > A_1 > A_4 > A_3$.

$\delta(A_i, A_j)$	Dominance Value	Total Dominance
$\delta(A_1, A_2)$	-2.324776514	
$\delta(A_1, A_3)$	-0.544183572	-3.875
$\delta(A_1, A_4)$	-1.006167146	
$\delta(A_2, A_1)$	-0.059509891	
$\delta(A_2, A_3)$	0.27367749	1.208
$\delta(A_2, A_4)$	0.994313732	
$\delta(A_3, A_1)$	-2.771381962	-9.214
$\delta(A_3, A_2)$	-4.583935895	

$\delta(A_3, A_4)$	-1.859241709	
$\delta(A_4, A_1)$	-3.728026642	
$\delta(A_4, A_2)$	-4.3226066	-8.954
$\delta(A_4, A_3)$	-0.90426378	

Table 8: Dominance of Alternatives

The ranking evaluation through rough-TODIM can be depicted through a flow chart as shown in Figure 4.

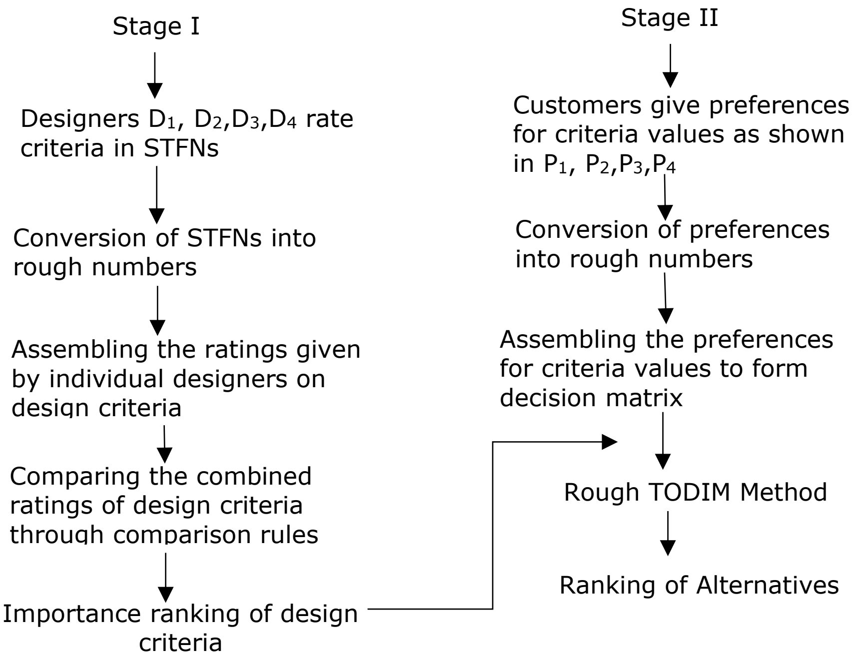

Figure 4: Procedure of Rough-TODIM.

Design Criteria	*Global Measurement*	*Ranking*
A_1	0.5122	Second

A_2	1	First
A_3	0	Fourth
A_4	0.0249	Third

Table 9: Global Measurement and Ranking of Alternatives

The best concept A_2 is an optimum choice based on rules proposed for calculating profit and loss to the designer during the decision-making process. It is a correct choice because the designer is in maximum gain condition when A_2's criteria values are selected in comparison to other alternative criteria values during concept evaluation. Also, A_2's criteria values are the most preferred by the customers for important design criteria and least preferred for low-important design criteria.

5 COMPARISON WITH OTHER METHODS

The proposed concept evaluation method is compared with other methods namely, the TODIM method developed by Gomes et al. [7] and interval-valued intuitionistic fuzzy TODIM developed by Krohling et al.[13] to demonstrate the effectiveness of the method. The ranking of the alternatives is calculated for θ values of 1 and 2.5 for the same case study of the weightlifting bench. The results are shown in Table 10. The proposed method captures both the subjective judgements of designers and linguistic preferences of customers in the form of rough numbers, whereas the method proposed by Gomes considers crisp values and Krohling uses interval-valued intuitionistic fuzzy numbers. The ranking computed by the proposed work is therefore different when compared with the other methods. Alternative A_2 comes out to be the best concept with the proposed method because A_2's criteria values if selected in comparison to the other alternative criteria values present the most gain to the designer and partial loss during the decision-making process. Also, A_2's criteria values are the most preferred (maximum gain) for the important design criteria, averagely preferred (partial gain) for medium important design criteria and least preferred (gain) for low important design criteria. The previously developed concept evaluation frameworks, which consider cost and benefit aspects of design criteria, do not give any information about the risk preferences of the designers (profit and loss) during the decision-making process.

θ Value	*Ranking computed by Proposed Rough-TODIM*	*Ranking computed by TODIM*	*Ranking computed by Fuzzy TODIM*
$\theta = 1$	$A_2 > A_1 > A_4 > A_3$	$A_3 > A_1 > A_2 > A_4$	$A_3 > A_1 > A_2 > A_4$
$\theta = 2.5$	$A_2 > A_1 > A_4 > A_3$	$A_3 > A_1 > A_2 > A_4$	$A_3 > A_1 > A_2 > A_4$

Table 10: Ranking of alternatives compared with other methods.

6 CONCLUSION

In this manuscript, the effectiveness of the concept evaluation process is improved by capturing the risk to the designer in terms of profit and gain while decision-making during the early stages of the design process. This helps in capturing the design intent effectively during the early design stage of the product development process. Also, the proposed Rough-TODIM method uses rough numbers which not only helps to reduce uncertainty but also captures the true perception of customers and effectively handles the subjective judgements of the designers. The alternative ordering achieved by the rough-TODIM method seems to be satisfactory as it considers the opinion of both the designers and customers during the design concept evaluation. Moreover, it also shows the psychological behavior of the designer during the concept evaluation process. The decision-making process is made effective by proposing the rules for computing the profit and loss to the designer in comparison to the previously developed concept evaluation frameworks, which only consider cost and benefit aspects of design criteria, and neglect the risk preferences of the designers.

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