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# Design Evaluation Framework for Design Engineers using Improved Rough-Grey Analysis – A case study

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**ABSTRACT**

In order to remain competitive in today's technologically driven world, the faster and more efficient development of innovative products has become the focus for manufacturing companies. In tandem with this, design evaluation plays a critical role in the early phases of product development, because it has significant impact on the downstream development processes as well as on the success of the product being developed. Owing to the pressure of primary factors, such as customer expectations, technical specifications and cost and time constraints, designers have to adopt various techniques for evaluating design alternatives in order to make the right decisions as early as possible. In this work, a new methodology for design evaluation has been developed. The preliminary stage quantifies all the criteria from different viewpoints through the process of scale of "Weighting criteria". The next stage uses a modified Rough-Grey Analysis to obtain the alternatives weighting or ranking of the alternatives. This method will enable designers to make better-informed decisions before finalising their choice. Case example from industry is presented to demonstrate the efficacy of the proposed methodology. The result of the example shows that this new method provides an alternative to existing methods of design evaluation.



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## INTRODUCTION

In today's industries, product design has become the main focus in a highly competitive environment and fast-growing global market (Turan & Omar, 2012; 2013). The benchmarks used to determine the competitive advantage of a manufacturing company are customer satisfaction, shorter product development time, higher quality and lower product cost (Hsu & Woon, 1998; Subrahmanian *et al*., 2005; Shai *et al*., 2007). Today's product designer is being asked to develop high-quality products at an ever increasing pace (Ye *et al*., 2008). To meet this challenge, new and novel design methodologies that facilitate the acquisition of design knowledge and creative ideas for later reuse are much sought after. In the same context, Liu & Boyle (2009) highlighted that the challenges currently faced by the engineering design industry are the need to attract and retain customers, the need to maintain and increase market share and profitability and the need to meet the requirements of diverse communities. Tools, techniques and methods are being developed that can support engineering design with an emphasis on the customer, the designer and the community (Chandrasegaran *et al*., 2013). Thus, a good design process should take into account the aforementioned criteria as early as possible in order to ensure the success of a product (Turan & Omar, 2012; 2013).

One important step in designing new products is generating conceptual designs (Turan & Omar, 2013). The conceptual design process includes a set of technical activities, which are the refinement of customer requirements into design functions, new concept development and the embodiment engineering of a new product (Li *et al*., 2010). A study by Lotter (1986) indicates that as much as 75% of the cost of a product is being committed during the design phase. In the same context, Nevins & Whitney (1989) surmise that up to 70% of the overall product development cost is committed during the early design phases. Furthermore, Ullman (2009) points out that 75% of the manufacturing cost is committed early in the design process. Under such circumstances, the design concept evaluation in the early phase of product development plays a critical role because it has a significant impact on downstream processes (Zhai *et al*., 2009). Similarly, Geng *et al*. (2010)

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point out that design concept evaluation, which is at the end of the conceptual design process, is one of the most critical decision points during product development. It relates to the ultimate success of product development, because a poor design concept can rarely be compensated in the latter stages.

Design concept evaluation is a complex multi-criteria decision-making process, which involves many factors ranging from initial customer needs to the resources and constraints of the manufacturing company. Concept design selection is the process of evaluation and selection from a range of competing design options with respect to customer needs and other criteria, comparing the relative strengths and weaknesses of the concept design and selecting one or more concept designs for further investigation, testing, or development (Green, 2000). However, how to evaluate effectively and objectively design concepts at the early stage of product development has not been well addressed, because the information available is usually incomplete, imprecise, subjective or even inconsistent (Rosenman, 1993). As such, the quest for more effective and objective approaches to evaluate systematically design concepts in the early stage of the design process has invoked much research interest.

In order to help designers become better-informed than conventional method prior to making a judgement, a systematic design evaluation method is needed. Amongst the various tools developed for design concept evaluation, fuzzy set theory and the Analytical Hierarchy Process (Fuzzy-AHP) methods have received the most attention owing to their abilities in handling uncertainty and multi-criteria decision making (MCDM) (Scott, 2002; Turan & Omar, 2013). Scott (2002) and Ayag & Odzemir (2007) state that AHP is one of the best methods for deciding among a complex criteria structure of different levels, whereas Fuzzy-AHP is a synthetic extension of the classical AHP method in which the fuzziness of the decision makers is considered. The nature of vagueness in design concept evaluation has made this method a topic of considerable interest to many researchers (Scott, 2002; Ayag & Odzemir, 2007). In accordance with this, an ideal design evaluation method, as espoused by Ayag & Odzemir (2007), Zhai *et al*. (2009) and Turan & Omar (2013), needs to use fewer numbers of design criteria.

In many practical situations, the human preference model is uncertain and decision makers might be reluctant or unable to assign exact numerical values to the comparison judgements. Although the use of the discrete scale for performing pair-wise comparative analysis has the advantage of simplicity, a decision maker might find it extremely difficult to express the strength of his preferences and to provide exact pair-wise comparison judgements in relation to the design criteria (Triantaphyllou & Lin, 1996; Duran & Aguilo, 2007). Consequently, the decision makers will need a process of reconsideration of design alternatives in relation to the design criteria, which might not help them reduce the number of design criteria. In addition, the final weight of design alternatives might not produce significant differences, which will affect the designers or decision makers when making a judgement.

The proposed design evaluation method will use a modified Rough-Grey Analysis method. A literature search indicates that no work has been done previously on the proposed methodology in design evaluation for new product development. The implementation of the proposed novel method will be divided into two stages: preliminary stage quantifies all the criteria from different viewpoints through the process of scale of "Weighting criteria", and next stage uses a Rough-Grey Analysis to obtain the alternatives weighting or ranking of the alternatives which use fewer numbers of design criteria.

As the overall aim is broad, it has been divided into single objectives in order to support its achievement. The objective of this research is to develop an improvement Rough-Grey Analysis method as the following steps:

1) Introduce the scale of "Weighting criteria" for survey process prior to the stage of design evaluation using the Rough-Grey Analysis method. Scale of "Weighting criteria" will quantify all the criteria from different viewpoints.
2) Introduce the method of quantifying the attribute ratings $\otimes v$ to carry out design evaluation using the Rough-Grey Analysis method.

The final target of the proposed approach is to help the design community become better-informed than conventional method before making final judgements and consequently, reduce development time and cost.

***Methodology:***

The general framework of the approach is as depicted in Figure 1. In this research, the new contribution, which is the scale of "Weighting criteria" for survey process is introduced. The data from results of survey will be used to quantify the attribute rating $\otimes v$ using the new method, which is another contribution in this research. Finally, the Rough-Grey Analysis method will be used for obtaining the weights of alternatives from the point of view of each decision maker.

***1) Scale of weighting criteria:***

The scale between 0 – 10 was developed to ease the respondents' group for rating the evaluation criteria, which initially selected by the design engineers based on technical documents and the results of a prior survey.

The rating value obtained from the survey then will be used to quantify the attribute ratings ⊗v at later stage. Table 1 describes the scale of "Weighting criteria" in more detail.

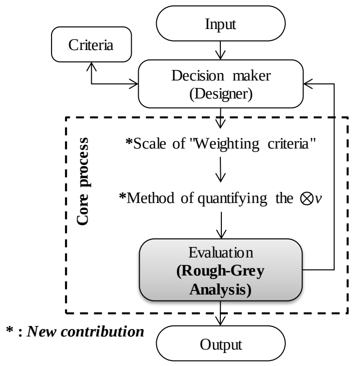


**Fig. 1:** General Framework of proposed approach.

**Table 1:** Scale of "Weighting criteria".

| Numerical rating | Description |
|---|---|
| 0 | Absolutely useless |
| 1 | Very inadequate |
| 2 | Weak |
| 3 | Tolerable |
| 4 | Adequate |
| 5 | Satisfactory |
| 6 | Good with few drawbacks |
| 7 | Good |
| 8 | Very good |
| 9 | Exceeding the requirement |
| 10 | Ideal |

***2) Method of quantifying the attribute ratings:***

The new method of quantifying the attribute ratings value, ⊗v as described in the following paragraph:

a) Develop the dummy attribute ratings chart for all top seven criteria as shown Table 2.

**Table 2:** Dummy attribute ratings chart.

| $a_j$ | $S_i$ | DM *1* | | | … | … | DM *K* | | |
|---|---|---|---|---|---|---|---|---|---|
| | | $v_{ij\ Typ.}$ | $v_{ij\ Min}$ | $v_{ij\ Max}$ | … | … | $v_{ij\ Typ.}$ | $v_{ij\ Min}$ | $v_{ij\ Max}$ |
| $a_1$ | $S_1$ | $V_{11}$ | $V_{11}$-0.5 | $V_{11}$+0.5 | … | .. | $V_{1K}$ | $V_{1K}$-0.5 | $V_{1K}$+0.5 |
| | $S_2$ | $V_{21}$ | $V_{21}$-0.5 | $V_{21}$+0.5 | … | … | $V_{2K}$ | $V_{2K}$-0.5 | $V_{2K}$+0.5 |
| | ... | … | … | ... | … | … | … | … | ... |
| | $S_n$ | $V_{n1}$ | $V_{n1}$-0.5 | $V_{n1}$+0.5 | … | … | $V_{nK}$ | $V_{nK}$-0.5 | $V_{nK}$+0.5 |
| … | | … | … | … | … | … | … | … | … |
| … | | ... | … | … | … | … | ... | … | … |
| $a_7$ | $S_1$ | $V_{11}$ | $V_{11}$-0.5 | $V_{11}$+0.5 | … | .. | $V_{1K}$ | $V_{1K}$-0.5 | $V_{1K}$+0.5 |
| | $S_2$ | $V_{21}$ | $V_{21}$-0.5 | $V_{21}$+0.5 | … | … | $V_{2K}$ | $V_{2K}$-0.5 | $V_{2K}$+0.5 |
| | ... | … | … | ... | … | … | … | … | ... |
| | $S_n$ | $V_{n1}$ | $V_{n1}$-0.5 | $V_{n1}$+0.5 | … | … | $V_{nK}$ | $V_{nK}$-0.5 | $V_{nK}$+0.5 |

where *Vi* refers to the rating value of evaluation criteria from respondents' survey results, *K* is the number of group of respondents and DM is abbreviation of decision maker.

b) Determine the $\underline{v}_{ij}$ and $\bar{v}_{ij}$ using the following formula:

$$\underline{v}_{ij} = \frac{1}{K}\left[v_{ij}{}^{1}{}_{Min} + v_{ij}{}^{2}{}_{Min} + \ldots + v_{ij}{}^{K}{}_{Min}\right] \tag{1}$$

$$\bar{v}_{ij} = \frac{1}{K}\left[v_{ij}{}^{1}{}_{Max} + v_{ij}{}^{2}{}_{Max} + \ldots + v_{ij}{}^{K}{}_{Max}\right] \tag{2}$$

***3) Procedure of the rough–grey analysis:***

The Rough-Grey Analysis approach is very suitable for solving the group decision-making problem in an environment of uncertainty. The attribute ratings ⊗v for benefit attributes are shown in Table 3.

The selection procedures are summarised as follows (Li *et al*., 2008; Bai & Sarkis, 2010, 2011):

a) Establishment of grey decision table.

Form a committee of DMs and determine attribute values of alternatives. Assume that a decision group has K persons and then the grey number value of attribute $\otimes v_{ij}$ can be calculated as:

**Table 3:** The scale of attribute ratings ⊗v for benefit attributes.

| Scale | ⊗v |
|---|---|
| Very poor (VP) | [0,1] |
| Poor (P) | [1,3] |
| Medium poor (MP) | [3,4] |
| Fair (F) | [4,5] |
| Medium good (MG) | [5,6] |
| Good (G) | [6,9] |
| Very good (VG) | [9,10] |

$$\otimes v_{ij} = \frac{1}{K}\left[\otimes v_{ij}^{1} + \otimes v_{ij}^{2} + \cdots + \otimes v_{ij}^{K}\right] = \left[\underline{v}_{ij}, \bar{v}_{ij}\right] \quad (3)$$

where $i$ refers to alternatives, while $j$ refers to different attributes; $\otimes v_{ij}^{K} = \left[\underline{v}_{ij}^{K}, \bar{v}_{ij}^{K}\right]$, $(i = 1,2,\cdots,m;\ j = 1,2,\cdots,n)$ is the attribute rating value of the $K$th DM that is expressed by a grey number.

b) Normalisation of grey decision table.

Form a committee of DMs and determine attribute values of:

$$\otimes v_{ij}^{*} = \left[\frac{\underline{v}_{ij}}{v_j^{\max}}, \frac{\bar{v}_{ij}}{v_j^{\max}}\right] \quad (4)$$

where $v_j^{\max} = \max_{1\le i\le m}\{\bar{v}_{ij}\}$

For cost attributes, its normalised grey number value $\otimes v_{ij}^{*}$ is expressed as:

$$\otimes v_{ij}^{*} = \left[\frac{v_j^{\min}}{\bar{v}_{ij}}, \frac{v_j^{\min}}{\underline{v}_{ij}}\right] \quad (5)$$

where $v_j^{\min} = \min_{1\le i\le m}\{\underline{v}_{ij}\}$.

The normalisation method mentioned above is to preserve the attribute that the ranges of normalised grey numbers belong to [0, 1].

***c) Determination of the suitable alternatives:***

In order to reduce unnecessary information and maintain the determining rules, we determine the suitable alternatives by a grey-based rough set with lower approximation. The lower approximation of suitable alternatives $S^*$ are determined by:

$$\underline{R}S^* = \{S_i \in U \mid [S_i]_R \subseteq S^*\} \quad (6)$$

where $S^* = \{S_i \mid d_i = yes\}$.

***d) Making the ideal alternative for reference:***

According to $\underline{R}S^*$ obtained from equation (6), we determinate the ideal alternative $S^{\max}$ for reference by:

$$S^{\max} = S_0 = \left\{\begin{matrix}\left[\max\limits_{\forall i} \underline{v}_{i1}^{*}, \max\limits_{\forall i} \bar{v}_{i1}^{*}\right], \\ \left[\max\limits_{\forall i} \underline{v}_{i2}^{*}, \max\limits_{\forall i} \bar{v}_{i2}^{*}\right], \\ \cdots, \left[\max\limits_{\forall i} \underline{v}_{im}^{*}, \max\limits_{\forall i} \bar{v}_{im}^{*}\right]\end{matrix}\right\} \quad (7)$$

***e) Selection the most suitable alternative:***

The grey relational coefficient (GRC) of $\otimes x_i$ with respect to $\otimes x_0$ at the $k$th attribute, is calculated as (Dang *et al.*, 2005):

$$\gamma\left(\otimes x_0(k), \otimes x_i(k)\right) = \frac{\Delta\min + \rho\Delta\max}{\Delta_{0i}(k) + \rho\Delta\max} \quad (8)$$

where

$$\Delta\max = \max_{\forall i, \forall k}\max L\left(\otimes x_0(k), \otimes x_i(k)\right) \quad (9)$$

$$\Delta\min = \min_{\forall i, \forall k}\min L\left(\otimes x_0(k), \otimes x_i(k)\right) \quad (10)$$

$$\Delta_{0i}(k) = L\left(\otimes x_0(k), \otimes x_i(k)\right) \quad (11)$$

$L\left(\otimes x_0(k), \otimes x_i(k)\right)$ is the Euclidean space distance of $\otimes x_0(k)$ and $\otimes x_i(k)$ which is calculated by equation below:

$$L(\otimes x_1,\otimes x_2)=\sqrt{(\underline{x}_1-\underline{x}_2)^2+(\overline{x}_1-\overline{x}_2)^2} \quad (12)$$

ρ is the distinguishing coefficient, ρ=[0, 1]. The grey relational grade (GRG) between each comparative sequence $\otimes x_i$ and the reference sequence $\otimes x_0$ can be derived from the average of GRC, which is denoted as:

$$\Gamma_{0i}=\sum_{k-1}^{n}\frac{1}{n}\gamma(\otimes x_0(k),\otimes x_i(k)) \quad (13)$$

where $\Gamma_{0i}$ represents the degree of relation between each comparative sequence and the reference sequence. Through the calculation of GRG between comparative sequences $\underline{RS}*$ with reference sequence $S^{\max}$, the alternative corresponding to the maximum value of GRG can be considered as the most suitable alternative.

***Case Study:***

This research presents an example from industry to demonstrate the efficacy of the proposed methodology. The application is to select the best front panel design for an internal media card reader from among six developed concept designs, which have been designed by the design engineers, as depicted in Figure 2. From the point of view of the design engineers, all six alternatives could potentially be manufactured. There are five decision makers whose views are deemed important and they should be taken into account for making a decision. They are the original equipment manufacturer (OEM) customers, distributors, sales department, manufacturing department and top management group. The actual completion period needs be confirmed at this stage.

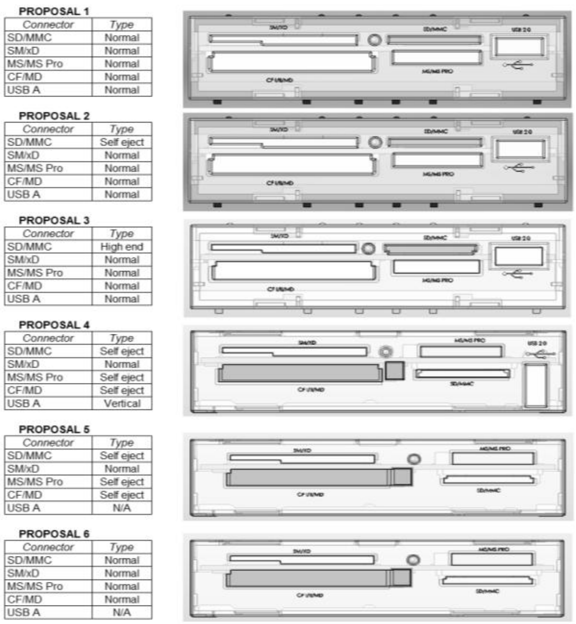


**Fig. 2:** Design alternatives for the case study.

***1) Survey results of evaluation criteria:***

Table 9 depicts the survey results of the respondents' group for rating the evaluation criteria using the new scale of "Weighting criteria" after selecting top seven criteria.

***2) Quantify the attribute ratings:***

Table 5 depicts the dummy attribute ratings chart which will help the designers to establish the grey decision table after quantifying the attribute ratings value, $\otimes v$.

***3) Evaluation using Rough-Grey Analysis:***

There is a grey information system $T=(U,A,V,f_{\otimes})$ for the selection of alternatives. The grey decision table is expressed by $T=(U,A\cup D,f_{\otimes})$. $U=\{S_i,i=1,2,...,6\}$ are six potential alternatives for seven attributes $A=\{a_j,j=1,2,...,7\}$. The seven attributes include qualitative attributes and quantitative attributes. $a_2$, $a_3$, $a_4$, $a_6$ and $a_7$ are benefit attributes, for which the larger values are better. $a_1$ and $a_5$ are cost attributes, for which the smaller values are better.

The GRA is a numerical measure of the relationship between the comparative values and objective values; the numeric values are between 0 and 1. By the rule that the design corresponding to the maximum value of GRG is the most suitable design, the grade is $S_6 > S_1 > S_2 > S_5 > S_3 > S_4$, as shown in Table 6.

**Table 4:** Survey results of evaluation criteria using scale of "Weighting criteria".

| Evaluation criteria | No | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|---|---|
| | | Mass and size | Simple assembly | Few producibility errors | Less numbers of spec control | Cost | Good performance | Good reliability |
| *OEM* | #1 | 7 | 4 | 3 | 3 | 5 | 5 | 5 |
| | #2 | 5 | 4 | 3 | 3 | 4 | 5 | 5 |
| | #3 | 5 | 4 | 3 | 3 | 3 | 5 | 5 |
| | #4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
| | #5 | 5 | 4 | 3 | 3 | 3 | 5 | 5 |
| | #6 | 7 | 4 | 3 | 3 | 5 | 5 | 5 |
| *Distributor* | #1 | 7 | 4 | 3 | 3 | 5 | 5 | 5 |
| | #2 | 5 | 4 | 3 | 3 | 4 | 5 | 5 |
| | #3 | 5 | 4 | 3 | 3 | 3 | 5 | 5 |
| | #4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
| | #5 | 5 | 4 | 3 | 3 | 3 | 6 | 5 |
| | #6 | 7 | 4 | 3 | 3 | 6 | 5 | 5 |
| *Sales* | #1 | 7 | 4 | 3 | 3 | 5 | 5 | 3 |
| | #2 | 5 | 4 | 3 | 3 | 4 | 5 | 3 |
| | #3 | 5 | 4 | 3 | 3 | 3 | 5 | 3 |
| | #4 | 4 | 3 | 3 | 3 | 3 | 3 | 2 |
| | #5 | 5 | 4 | 3 | 3 | 3 | 5 | 3 |
| | #6 | 7 | 4 | 3 | 3 | 5 | 5 | 3 |
| *Top management* | #1 | 7 | 4 | 4 | 3 | 5 | 5 | 5 |
| | #2 | 5 | 4 | 4 | 3 | 4 | 5 | 5 |
| | #3 | 5 | 4 | 4 | 3 | 3 | 5 | 5 |
| | #4 | 4 | 3 | 3 | 3 | 3 | 3 | 3 |
| | #5 | 5 | 4 | 4 | 3 | 3 | 5 | 5 |
| | #6 | 7 | 4 | 4 | 3 | 6 | 5 | 5 |
| *Manufacturing* | #1 | 7 | 5 | 4 | 3 | 5 | 5 | 5 |
| | #2 | 5 | 5 | 4 | 3 | 4 | 5 | 5 |
| | #3 | 5 | 5 | 4 | 3 | 3 | 5 | 5 |
| | #4 | 4 | 3 | 3 | 2 | 3 | 3 | 3 |
| | #5 | 5 | 5 | 4 | 3 | 3 | 5 | 5 |
| | #6 | 7 | 5 | 4 | 3 | 5 | 5 | 5 |

***Conclusions:***

The appropriate integration of more than one theory, as suggested in this research, could overcome the individual shortcomings of their definitions and applications. The satisfactory performance of the various existing methods in the design evaluation process cannot be guaranteed easily, because the selected method should have the capability of accommodating the uncertainties and vagueness of the design criteria. If these issues cannot be solved, it will lead to the unnecessary backtracking process in the criteria evaluation process, which will delay the evaluation process.

The main objective of this research was to develop a novel methodology for design evaluation that enables designers to become better informed than conventional method before finalising their choice by using modified Rough-Grey Analysis. As described in methodology section, the solution to achieve this main objective was to introduce the the used of scale of "Weighting criteria" for survey process into the preliminary stage of the design evaluation process. The data from results of survey will be used to quantify the attribute ratings value using new method prior to the evaluation process using the Rough-Grey Analysis method. The prospective benefit of this new method is that it can help designers to reduce the risk of late design changes or corrections.

The results of the example presented in this research show that the idea of using the integration and interfacing technique of scale of "Weighting criteria" and Rough-Grey Analysis, provides designers with another alternative to the existing methods, for the performance of design evaluation in the early stages of product development. The proposed framework has successfully helped the designers to reduce product development time and cost and thus, create value for the company. This work is also the first work that uses a modified Rough-Grey Analysis for design evaluation in product development.

Although the analysis and methodologies provided are quite good and constitute a set of powerful tools by which to guarantee the requirements of the design evaluation, some improvements could still be made.

In this research, the weight or ranking of alternatives using Rough-Grey Analysis will be accepted. However, the difference from the viewpoint of each stakeholder was not considered. Thus, the proposed method could be enhanced by including the aggregation process of stakeholder viewpoints by using the appropriate method.

**Table 5:** Dummy attribute ratings chart for all top seven criteria.

| $a_j$ | $S_i$ | *OEM customer* | | | *Distributor* | | | *Sales* | | | *Top management* | | | *Designer* | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Typ* | *Min* | *Max* | *Typ* | *Min* | *Max* | *Typ* | *Min* | *Max* | *Typ* | *Min* | *Max* | *Typ* | *Min* | *Max* |
| $a_1$ | $S_1$ | 7 | 6.5 | 7.5 | 7 | 6.5 | 7.5 | 7 | 6.5 | 7.5 | 7 | 6.5 | 7.5 | 7 | 6.5 | 7.5 |
| | $S_2$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_3$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_4$ | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 |
| | $S_5$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_6$ | 7 | 6.5 | 7.5 | 7 | 6.5 | 7.5 | 7 | 6.5 | 7.5 | 7 | 6.5 | 7.5 | 7 | 6.5 | 7.5 |
| $a_2$ | $S_1$ | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 5 | 4.5 | 5.5 |
| | $S_2$ | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 5 | 4.5 | 5.5 |
| | $S_3$ | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 5 | 4.5 | 5.5 |
| | $S_4$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_5$ | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 5 | 4.5 | 5.5 |
| | $S_6$ | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 5 | 4.5 | 5.5 |
| $a_3$ | $S_1$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 |
| | $S_2$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 |
| | $S_3$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 |
| | $S_4$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_5$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 |
| | $S_6$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 |
| $a_4$ | $S_1$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_2$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_3$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_4$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 2 | 1.5 | 2.5 |
| | $S_5$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_6$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| $a_5$ | $S_1$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_2$ | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 | 4 | 3.5 | 4.5 |
| | $S_3$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_4$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_5$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_6$ | 5 | 4.5 | 5.5 | 6 | 5.5 | 6.5 | 5 | 4.5 | 5.5 | 6 | 5.5 | 6.5 | 5 | 4.5 | 5.5 |
| $a_6$ | $S_1$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_2$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_3$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_4$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_5$ | 5 | 4.5 | 5.5 | 6 | 5.5 | 6.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_6$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| $a_7$ | $S_1$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 3 | 2.5 | 3.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_2$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 3 | 2.5 | 3.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_3$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 3 | 2.5 | 3.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_4$ | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 | 2 | 1.5 | 2.5 | 3 | 2.5 | 3.5 | 3 | 2.5 | 3.5 |
| | $S_5$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 3 | 2.5 | 3.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |
| | $S_6$ | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 | 3 | 2.5 | 3.5 | 5 | 4.5 | 5.5 | 5 | 4.5 | 5.5 |

**Table 6:** Grey relational grade for proposed method.

| GRG | Conditional attributes | | | | | | | Total | Ranking |
|---|---|---|---|---|---|---|---|---|---|
| | $a_1$ | $a_2$ | $a_3$ | $a_4$ | $a_5$ | $a_6$ | $a_7$ | | |
| □$_{01}$ | 0.167 | 0.167 | 0.167 | 0.167 | 0.139 | 0.151 | 0.167 | 1.123 | 2 |
| □$_{02}$ | 0.055 | 0.167 | 0.167 | 0.167 | 0.069 | 0.151 | 0.167 | 0.943 | 3 |
| □$_{03}$ | 0.055 | 0.167 | 0.167 | 0.167 | 0.000 | 0.151 | 0.167 | 0.873 | 5 |
| □$_{04}$ | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 6 |
| □$_{05}$ | 0.055 | 0.167 | 0.167 | 0.167 | 0.000 | 0.167 | 0.167 | 0.889 | 4 |
| □$_{06}$ | 0.167 | 0.167 | 0.167 | 0.167 | 0.167 | 0.151 | 0.167 | 1.151 | 1 |

This research not only benefits the area of design evaluation in product development but it can be applied to any other area associated with a decision-making process. The efficacy of the proposed method could be extended by applying it in different conditions or to products of different complexity.

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