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Design Evaluation Method for Design Engineer in Manufacturing Industries using Integrated Rough-Grey Analysis Approach

Faiz Mohd Turan [1, a *] and Badrul Omar [2,b]

[1] Faculty of Manufacturing Engineering, Universiti Malaysia Pahang, 26600 Pekan, Pahang, Malaysia

[2] Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

[a]faizmt@ump.edu.my, [b]badrul@uthm.edu.my

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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.

Introduction

In today's industries, product design has become the main focus in a highly competitive environment and fast-growing global market [1, 2]. 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 [3] 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 [4].

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. In order to help designers become better-informed 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) [1, 5]. However, in many practical situations, 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.

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.

Methodology

The general framework of the approach is as depicted in Fig. 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.

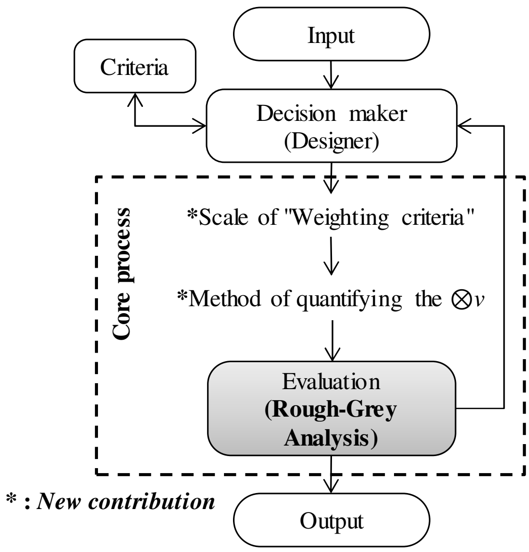

Fig. 1: General Framework of proposed approach

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 $\otimes v$ at later stage. Table 1 describes the scale of "Weighting criteria" in more detail.

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.

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]

The selection procedures are summarised as follows:

a) Establishment of grey decision table. Form a committee of DMs and determine attribute values of alternatives.
b) Normalisation of grey decision table. The normalisation method 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.
d) Making the ideal alternative for reference.
e) Selection the most suitable alternative. The alternative corresponding to the maximum value of grey relational grade (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 mould design for a video camera's top cover from among three developed concept designs, which have been designed by the design engineers, as depicted in Figure 2. There are five decision makers whose views are deemed important and they should be taken into account for making a decision. They are production, maintenance, engineering, quality control and the production control department.

MOULD DESIGN 1

Type of mould	3-plate
Number of cavities	4
Mould insert material	P5
Types of gates	pin point gate
Types of ejection system	stripper plate
Cooling systems	spiral cooling

MOULD DESIGN 2

Type of mould	3-plate
Number of cavities	4
Mould insert material	P5
Types of gates	pin point gate
Types of ejection system	ejector pin
Cooling systems	spiral cooling

MOULD DESIGN 3

Type of mould	3-plate
Number of cavities	2
Mould insert material	P5
Types of gates	pin point gate
Types of ejection system	stripper plate
Cooling systems	spiral cooling

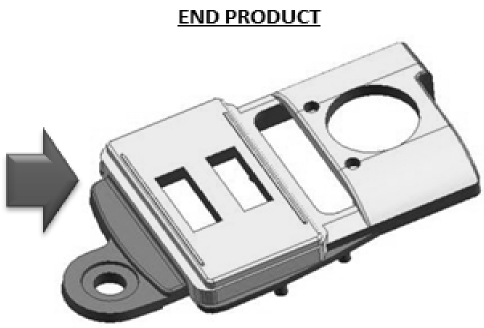

Fig. 2: Design alternatives for the case study

The GRA is a numerical measure of the relationship between 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 $S_1 > S_2 > S_3$, as shown in Table 4. This is an evaluation process using the integration of Scale of weighting criteria, Method of quantifying the attribute ratings and Rough-Grey analysis method (Core process). From the GRG results, the most suitable design is Design 1 $(\Gamma_{01} = 1.000)$, followed by Design 2 $(\Gamma_{02} = 0.667)$ and Design 3 $(\Gamma_{03} = 0.333)$.

Table 4: 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		
Γ_{01}	0.333	0.333	0.000	0.000	0.333	0.000	0.000	1.000	1
Γ_{02}	0.333	0.000	0.000	0.000	0.333	0.000	0.000	0.667	2
Γ_{03}	0.000	0.333	0.000	0.000	0.000	0.000	0.000	0.333	3

Summary

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 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. 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.

a) 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.
b) 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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