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Product design concept evaluation using rough sets and VIKOR method

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ABSTRACT

Design concept evaluation is one of the most important phases in the early stages of the design process as it not only significantly affects the later stages of the design process but also influences the success of the final design solutions. The main objective of this work is to reduce the imprecise content of customer evaluation process and thus, improve the effectiveness and objectivity of the product design. This paper proposes a novel way of performing design concept evaluations where instead of considering cost and benefit characteristics of design criteria, the work identifies best concept which satisfy constraints imposed by the team of designers on design criteria's as well as fulfilling maximum customers' preferences. In this work, the rough number enabled modified Vlsekriterijumska Optimizacija I Kompromisno Resenje (VIKOR) method for design concept evaluation is developed by modifying the extended VIKOR method with interval numbers. The proposed technique is labeled as modified rough VIKOR (MR-VIKOR) analysis. The work primarily involves two phases of concept evaluation. In the first phase, relative importance ranking and initial weights of design criteria are computed through the importance assigned to each design criteria by the designers or the decision makers (DM); and in the second phase, customers' preferences to the generated user needs are captured in the form of rough numbers. The relative importance ranking computed in first phase along with customers' preferences is incorporated in the second phase to select the best concept.

1. Introduction

Concept evaluation is an important stage in the design process as it helps to assess the overall utility of design alternatives against the design objectives. Early concept evaluation can save both time and cost as 80% of overall product quality and 70–80% of product development cost is committed in the early stages of the design process [1–4]. The importance of design concept evaluation is obvious because the poor selection of a design concept can hardly ever be compensated at later stages of design process and may lead to large redesign costs [5]. Concept evaluation is a complex multi-criteria decision making problem inherent with a number of difficulties. Decision making during this process is hindered due to the complexity of problem solving, handling of conflicting decision-making criteria and assessment of product performance [6]. The need to incorporate highly subjective customer preferences in evaluation process, evaluation of trade-offs between conflicting design criteria, subjective judgments of experienced designers (or decision makers), calculating degree of satisfaction level of customers against the generated design alternatives and performance capabilities of design alternatives in terms of meeting the final technical specifications introduces various degree of uncertainty in the concept evaluation process.

The main design objectives that helps to determine the success of the final design concept (design solution) are customers' satisfaction, product development time and product cost. A designer should embrace these objectives in the design process to ensure competitive advantage in the fast growing market. Many previous concept evaluation frameworks consider customer satisfaction as most important objective, but most of the times, out of the real requirements specified by the customers, majority of the requirements are of poor quality. They are inconsistent, vague, infeasible to implement or manufacture, besides being not really mandatory, unverifiable and unobtainable. Poor quality requirements results in increase in product development time and cost besides leading to mistakes which have negative impact during the subsequent downstream design activities. Many a times, customer demands specification in a product without considering cost and benefit characteristics of design criteria and designer has to implement features in a product merely because user swore they

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needed badly, but after sometimes the user loses interest. Thus, considering only customer satisfaction during the concept evaluation phase of product design does not make the design process effective. It is required to give equal importance and incorporate customers' requirements as well as designers' limitation (or company constraints) for the success of the final design concept(s).

Earlier most of the concept evaluation frameworks consider cost and benefit characteristics of design criteria and select the best concept which performs the best based on these conflicting criteria. This paper considers importance level of design criteria (very high, high, medium and low) based on the judgments given by a team of designers, and thus proposes a different and novel way of concept evaluation. This method identifies the best concept that can fully satisfy designers or company specific constraints based on importance level of design criteria as well as maximize customer satisfaction. The proposed framework proves to be useful, during early stages of design when information about many attributes is not clear. With the help of proposed work, designers can easily find which concept is most preferable for certain important design attributes and least preferred for the uncertain design attributes. The work primarily involves two phases for concept evaluation. In the first phase, the rough numbers introduced by Zhai et al. [7] are used to calculate relative importance ranking and rating of conflicting design criteria from the team of designers' vague judgements. In the second phase, these computed ranking of design criteria in terms of importance level (designers' constraints) and highly subjective customer preferences for design specifications captured in the form of rough numbers is incorporated in the framework of extended VIKOR method with interval numbers [8] to evolve a new concept evaluation technique, labelled as, modified rough VIKOR (MR-VIKOR) analysis. The use of rough numbers would improve the overall effectiveness and help the designers to take good decisions in an uncertain environment.

2. Previous work

Two approaches, numerical and non-numerical, are developed by the designers to solve complex multi-criteria decision making (MCDM) problem of concept evaluation [9,10]. Non-numerical methods are graphical based methods, which are simple, effective and easier to use for quick selection of design concepts, but this approach have lower efficiency and accuracy as compared to the numerical approach. Some of the non-numerical methods are concept screening [11] and Pugh charts [12]. These approaches do not effectively deal with uncertain, vague and subjective judgement of the decision maker. Numerical approaches support both quantitative and qualitative judgement of design criteria by the decision makers. Utility function analysis [13,14] and goal programming [15,16] allows judgement of decision maker to be expressed in quantitative form only. The limitation of these approaches is that it is very difficult to represent some intangible design criteria and factors in quantitative form accurately during early design stages [13,14]. Other category of numerical approach for example, Fuzzy set theory and Analytical Hierarchy process (AHP) allows decision maker's judgement to represent in both quantitative and linguistic form.

King and Sivaloganathan [17] have classified concept selection into five categories i.e. utility theory, AHP, graphical tools, quality function deployment (QFD) and fuzzy logic method. Among these approaches developed so far, AHP and fuzzy set theory have been mostly used by the researchers due to their ability to handle uncertainty [18]. Integrated decision making method is preferred over single MCDM method to solve efficiently the problem of concept evaluation. Huang et al. [19] used fuzzy sets with neural network and genetic algorithm to propose an integrated approach to solve the concept evaluation problem. This approach has lengthy training process and unable to solve real world problems due to complex and difficult algorithm structure. Fuzzy set theory supports favouring evidence only, and does not allow the designer to express hesitancy degree. Geng et al. [10] have proposed integrated concept evaluation method based on vague set theory where linguistic judgements of decision makers are transformed into vague numbers. Modified weighted least square model (WSLM) is used to combine all the judgements and techniques for order preference by similarity to ideal solution (TOPSIS) are proposed to rank the design concepts. The advantage of using vague set theory is that it supports both favouring and opposing evidences in achieving subjective judgement of the designer. Zhai et al. [9] proposed an integrated approach to improve subjectivity in concept evaluation process by combining rough set theory [20] and grey relation analysis.

AHP and simulation analysis is combined by Ayag [21] and proposed an integrated approach to perform design concept evaluations. Song et al. [22] proposed a hybrid approach in which rough numbers and AHP are combined for evaluating criteria weights of alternatives; and rough numbers and TOPSIS are combined to select the best alternative. AHP can be time consuming process with increase in the number of design criteria and alternatives. Large number of criteria results in large pair wise comparisons and huge evaluation matrix [23,24]. There is strict requirement to control consistency in pair wise comparisons of criteria's at higher levels, as AHP at lower levels of consistency does not produce correct results [25]. Besides fuzzy set and AHP, some other theories have also been used by designers for design evaluations. Yang and Sen [26] developed evidence reasoning approach based on Dempster–Shafer theory of evidence to perform design concept evaluation. Evidence reasoning approach does not efficiently model vague subjective judgement during design evaluation [22].

It is clear from the above discussions, that many methods are developed so far to perform design concept evaluations but except a few methods which are effective in some cases, many methods fails or lacks the support to effectively represent designers' and decision makers' vague perception, and uncertain and subjective information.

3. Rough numbers

One of the challenges which are faced by researchers today in the field of fuzzy set theory is selection of membership function which is a necessary requirement for effective performance of the fuzzy system [27]. This work proposes the use of rough numbers based on rough set theory, to reduce the vague and subjective perception of designer in concept evaluation process. Rough set theory [20] is a mathematical tool which was proposed to take advantage of information inherent in a given data without requiring any auxiliary information or subjective judgement (e.g. membership functions in the case of fuzzy set theory) for analysis of data. It uses approximation operators like approximation space, lower and upper approximations of a set to deal with vagueness and uncertainty [28]. In general, rough set theory uses a set of objects comprising multi-valued attributes to analyse any data. This structure of objects is called an information table.

Zhai et al. [7] defined rough numbers and rough boundary interval through the use of upper and lower approximations which is extended from basic rough set theory. Mathematically, the rough numbers are defined in the following way:

All the objects described by multi-attributes in any information table are represented by universe U. A set of n classes, i.e., $R = \{C_1, C_2, \ldots, C_n\}$ ordered in the manner of $C_1 < C_2 < \cdots < C_n$