Chapter 46
MCDM-Based Decision Support System for Product Design and Development

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Abstract The process of product design and development (PDD) consists of various sequential stages. Each stage requires a complex evaluation and the right decision to attain a successful product. Decision making in these product design stages often is involved with multiple criteria and it is important to use multiple criteria decision making (MCDM) to assist design practitioners for more appropriate decisions. Nowadays, various MCDM methods are available and applied in various areas. The objective of this paper is to identify the types of decision-making problems that may creep during different design stages and possible MCDM methods that might be applicable to solve them. This paper presents comparative analysis and gives information about some of the most popular MCDM methods with the design decision applications as per the available literature. This knowledge can help enterprises make better decisions in a particular design stage to ensure the success of their PDD.

46.1 Introduction

Product design and development (PDD) is a problem-solving and knowledge-accumulation process. This process passes through several key design stages before it gets a final design. Each design stage requires valid inputs and complex evaluation with clear decision making to obtain the desired output(s). Hence, PDD is a complex, interdisciplinary, sequential, uncertain, and risky process of extensive planning and activity. The right decisions in each design stage are vital to the success of the 'design.' A good product design ensures, product working as per customer requirements (CR), within optimal cost. To take the right decision by identifying, a feasible combination of customer requirements and satisfy the conflicting requirements is a tough task for both the design practitioners and the manufacturer [1]. Nowadays,

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product design has grown rapidly in the last few years. Increased competition for better product (or system) functionality, quality, and cost along with shorter delivery time presents remarkable challenges for any product manufacturing enterprise [2]. Over the past decades, the complexity of product design has increased rapidly.

The complex and dynamic nature of design leads to uncertainty and risk, which makes taking the right decision critical [3]. Most of the design problems often include the necessity to identify the best optimal design solution from a large number of potentially good alternative solutions. The selection of one good alternative among a large number of potential alternatives is a very critical managerial task. It is also challenging due to, design decision involves multiple criteria, both quantitative and qualitative in nature with dependent and independent variables.

Decision making in product design often is involved with multiple criteria. Therefore, it is advantageous to use multiple criteria decision making (MCDM) methods to find an appropriate assessment. During the past few years, there have been tremendous attempts on using MCDM techniques for decision making in product design. The implementation of MCDM could pave the way for a new horizon in the decision support system for product design. MCDM techniques improve the quality of decisions by creating the development more efficient, rational, and explicit [4]. As per the Wang, an optimal design scheme not only improves the performance of the product but also lead to the greatest satisfaction of customers [5]. In recent decades, the MCDM techniques and approaches have received a great deal of attention from design practitioners.

Nowadays, a large number of MCDM techniques have been proposed, which are diverse in their theoretical process, the type of input required, and the type of obtained results. Thus, it is important to identify the types of different MCDM techniques applicable in the product design and document the exponentially grown interest in the MCDM techniques and provide a state-of-the-art review of the literature regarding the MCDM applications for decision making in product design. This work gives an idea to identify suitable MCDM techniques for accurately and efficiently decision making in product design.

The remaining sections of this paper are organized as follows. Section 2 provides a summary of the literature review on decision making in product design. Section 46.3 describes the research methodology and the procedure of this study. Section 46.4 presents the discussion. Finally, Sect. 46.5 presents the conclusion and shows the prospects for future research framework, opportunities, and challenges.

46.2 Summary of the Literature

PDD process is a sequence of steps or stages to conceive design and commercialize a product. The decision making in PDD is considered as a typical MCDM problem. Due to the great interest of academics and practitioners, many efforts have been devoted to develop various types of MCDM methods. As per the literature, methods which are mostly used in design evaluation and decision making are: analytical hierarchy process (AHP) [6], analytic network process (ANP) [7], elimination and choice translating reality (ELECTRE) [8], goal programming (GP) [9], multi-attribute utility theory (MAUT) [10], preference ranking organization method for enrichment evaluation (PROMETHEE) [11], technique for order preference by similarity to ideal solutions (TOPSIS) [12], and weighted sum method (WSM) [13]. However, it is very challenging to decide which MCDM method is the best for the particular design problem. To date, several articles carried out a systematic review of the literature [14–17] on MCDM methods. Siskos and Spyridakos (1999) presented a survey of the history and the recent status of the multiple criteria decision support systems [14]. Zavadskas & Turskis presented a panorama of decision-making methods in light of the recent developments of multiple criteria decision-making methods [15]. Recently, Mardani et al. [16] reviewed a total of 393 articles published from 2000 to 2014 and investigated the developments of various methods of MCDM and their applications. Renzi et al. [16] presented a review of decision-making methods focused on the selection of decision support methods for automotive industry design problems. Nowadays, one MCDM method with a combination of other methods of MCDM methods has been proposed in the literature extensively and solved decision problems. Similarly, Mayyas et al. [17] proposed a combined quality function deployment and analytical hierarchy process; Peng and Xiao [18] proposed combined ANP and PROMETHEE; Zhou et al. [19] proposed AHP and TOPSIS for the suitable decisions. A method, which is often combined with the MCDM methods, is the fuzzy sets theory [16]. Fuzzy logic employed approximate modes of reasoning for decision making in imprecise and uncertain environment over the entire design cycle [20]. A further AHP method is most popular among the MCDM methods and frequently combined with the other MCDM [21]. AHP is a simple method that focuses on prioritizing the criteria by capturing the degree of importance of criteria to assist enterprises in the product development phase [22]. AHP is simple to use, flexible, effective, versatile, and transparent methods. This has made AHP extremely important and useful tools in solving design decision-making problems.

As per the literature, numerous MCDM methods are available, and no single method is considered the most suitable for all types of decision-making situations [22–24]. Moreover, different MCDM methods can yield different results when applied to the same design decision problem. Further, the selection of an appropriate decision-making method leads to an MCDM problem itself. Thus, it is felt that there is a serious need to classify the MCDM method as per the product design stages.

46.3 Research Methodology

The methodology of the work includes:

Step 1: Identification of strength, weaknesses, and application area of MCDM methods.

Step 2: Classification of various design stages and decision problems.

Step 3: Mapping of seven design stages and applicable MCDM methods.

46.3.1 Identification of Strength, Weaknesses, and Application of MCDM Methods

For the aforementioned goal, the article reviews the literature published in popular journals on decision making in product design. An extensive search was carried out to find MCDM in titles, abstracts, keywords, and research methodologies of the article. Currently, research on MCDM continued and found many applications in different fields. Each of these methods has its own features and application area. After a comprehensive analysis of journal articles, it was found that the eight most frequently used techniques in PDD are: WSM, MAUT, AHP, ANP, TOPSIS, ELECTRE, GP, and PROMETHE. Based on the extensive literature reviewed, the observed strength and weaknesses, as well as application areas of the popular MCDM methods, are compiled in Table 46.1. As several types of MCDM methods are available and applied in various areas, this work considers only the major application areas.

46.3.2 Classification of Various Design Stages and Decision Problems

As shown in Table 46.1, MCDM methods have their own strength and weakness as well as application fields; none of the methods dominate the other methods. PDD process involves a systematic series of design stages that design practitioners follow to develop an appropriate design solution. During this process, there are numerous decisions made in every design stage to attain a successful design. Inappropriate decision making during any design stage may lead to product failure [3]. Therefore, in this section, the major stages of product design are classified and associated decision-making problems are identified. Many PDD process has been published over the years. Therefore, it is important to establish the comprehensive PDD process to conceive, design, and commercialize a product. As per the inputs gained from Ulrich and Eppinger [35], Pahl and Beitz [36], Anderson and Pine [37], Montagna [38], the seven major stages of PDD and associated decision-making problem are established as shown in Table 46.2 (column 1 to column 3). As per the available literature, the relationship between the features of the reviewed methods presented in Table 46.1, and the decision-making problems that characterize the design process in Table 46.2. There are many decision-making activities involved in each of the seven design stage. However, this work considered only the major decision-making job involved in the associated design stage.

Table 46.1 MCDM methods, their application, strength, and weakness

Methods	Area of application	Strength	Weakness	References
WSM	• Structural optimization • Product assessment • Fund allocation	• Risks and uncertainty are considered • Mechanism of the method is straight forward	• Needs a lot of input • Preferences need to be precise	[13, 25]
MAUT	• Supplier selection • City planning • Testing and robustness assessment	• Represent the uncertainty directly to decision model	• Needs a lot of input	[10, 26]
AHP	• Concept selection • Buyers selection • Customer needs selection • Resource management	• Flexible, intuitive appeal to the decision makers • Ability to check inconsistencies • Capture both subjective and objective evaluation measures	• Allows less number of alternatives • Expressed in different measurements	[1, 22, 27]
ANP	• Concept selection and evaluation • Supplier selection • Material selection • Site selection	• Allows complex interrelationships among decision levels and attributes • Allows tangible as well as intangible criteria in decision making	• Data acquisition is a time intensive process • Subjectivity of the comparisons is not considered • Requires a lot of calculations	[7, 16, 29]
TOPSIS	• Technology forecasting • Concept selection • Competitive benchmarking • Plant layout design	• Simple, rational, comprehensibility • Good computational efficiency and ability to measure the relative performance in a simple mathematical form	• Basically works on Euclidian distance and so does not consider any difference between negative and positive values	[1, 12, 28]
ELECTRE	• Business policy and strategy • Risk and financial management • Facilities planning	• Takes uncertainty and vagueness into account • Deals with heterogeneous scales	• Less versatile	[8, 30, 31]

(continued)

Table 46.1 (continued)

Methods	Area of application	Strength	Weakness	References
GP	• Product planning • Production planning • Cost estimation	• Capable of handling large-scale problems • Effective in combination with other MCDM methods	• Demands substantial information from decision makers on their objectives	[9, 32, 33]
PROMETHE	• Plant location selection • Concept selection • Resource evaluation	• Deals with qualitative and quantitative information • Incorporate uncertain and fuzzy information	• Output depends on the decision maker to assign weight	[11, 18, 34]

Table 46.2 PDD stages and associated MCDM methods

Product development stage	Involve decision	Methods
1. Planning	Business policy and strategy, fuzzy and conflict customers' requirements, risk and financial management	ELECTRE [31, 39], GP [32, 33]
2. Concept generation and selection	Technology forecasting, concept and functional analysis	AHP [22, 27] ANP [18, 29], TOPSIS [1, 19, 28], PROMETHE [11, 34]
3. Embodiment and detail design	product architecture, configuration, parametric, and material	TOPSIS [1, 28], WSM [13, 25], AHP[22, 27]
4. Testing and refinement	Performance, reliability, and durability	PROMETHE [11, 34], WSM [13, 25], MAUT [10, 26]
5. Production ramp-up	Resource management and utilization	AHP [22, 27], TOPSIS [1, 19, 28], GP [32, 33]
6. Approval and launching the product	Product demands, logistics, and transportation	AHP [23, 28], TOPSIS [1, 19, 28], PROMETHE [11, 34]
7. Planning for its retirement	Business management	ELECTRE [31, 39], GP [32, 33]

46.3.3 Mapping of MCDM Methods and Seven Stages of Design

Nowadays, a several MCDM methods available and each method are appropriate for some specific types of decision-making situation. The last phase of this work involves the mapping of the product design stage along with the associated MCDM methods (as obtained in Table 46.1). Based on the areas of application, the popular MCDM methods that are applicable to the particular product development stage are summarized in Table 46.2.

46.4 Discussion

An explicit decision-making process is one crucial aspects of efficient project execution in PDD. As shown in Sect. 46.3, WSM, MAUT, AHP, ANP, TOPSIS, ELECTRE, GP, and PROMETHE methods are well known, often cited, and commonly used MCDM methods for the decision making in PDD.

The first stage of the design process is the planning. This step undertakes to need assessment and viability of the project idea along with customer requirements decision. Further, designing a new product requires extensive planning. The early works had indicated that ELECTRE [31, 39] and GP [32, 33] are useful tools for handling decision making in the planning stage. The subsequent step of the design process begins with concept generation and concept selections. This stage is associated with knowledge and information processing to generate concepts, and thereafter, technical and economic feasibility investigation to select the most optimal concept. The excellence of the decision in this stage greatly impacts on the quality, cost, and desirability of the final product. In this stage, if the wrong concept is chosen, the design may be said to suffer from conceptual weakness. The available literature indicated that AHP [22, 27], ANP [18, 29], TOPSIS [1, 19, 28], and PROMETHE [10, 34] are some of the popular decision-making tools that can be employed in determining the most appropriate design concept.

Embodiment design and detail design are the subsequent step in the design process. Decision-making activity involves in this stage are: arrangement of the physical functions, selection of materials and size of parts, selection of final dimensions/parameters and tolerances, etc. As per the literature, methods that are mostly used for decision making during the embodiment design and detail design stage are TOPSIS [1, 28], WSM [13, 25], and AHP [22, 27]. During the testing and refinement stage, a number of prototypes are built and tested to examine the desired functionality. This stage involves compatibility with mating components, product performance, reliability, durability, etc. Literature proposes that PROMETHE [11, 34], WSM [13, 25], and MAUT [10, 26] are the most suitable MCDM methods to improve decision making during the testing and refinement stage. In the consequent stage, production ramp-up is the beginning of commercial production. The decision-making activity involves in the production ramp-up stage are: quality, equipment, technique, process, personnel, training, materials supply, volume, yield, cost, etc. As per the available literature, the techniques AHP [22, 27], TOPSIS [1, 28, 29], and GP [32, 33] offer enough scope for the decision making in the production ramp-up design stage. The next stage in the design process is the approval and launching. Decisions regarding, launch date, pricing and packaging, positioning, communications plan, marketing content, media relations, infrastructure, sales strategy, and training, are some of the crucial factors in this stage. Literature proposes AHP [23, 28], TOPSIS [1, 20, 29], and PROMETHE [11, 34] have been successfully applied for decisions related to product approval and launching. The last step in the design process is the product retirement. This stage is the end of the product life cycle. The decision for product retirement mostly depends on the product performance, technology progress, sales growth, market, competition, etc. Literature highlights that ELECTRE [31, 39] and GP [32, 33] techniques have been successfully applied for the decision making in the product retirement stage.

46.5 Conclusion

This paper carried out a unique literature review to identify the decision-making problem that may creep during different design stages and the MCDM methods that might be used to solve the decision problem. This work found that MCDM methods have rapidly developed and have been applied to support strategic decisions in various stages of PDD. It is also highlighted that each MCDM methods have their own strength and weakness as well as application fields. Accordingly, this work categorizes the associated MCDM techniques for optimum decision making in different product design stages. It is felt that the design practitioners may benefit from this work as they can identify what type of decision-making activity involves during a particular design stage, along with the MCDM methods that can be used for optimum decision making. In the literature review, it is observed that AHP was the most regular technique followed by TOPSIS and then PROMETHEE in PDD.

The study is limited to find most individual MCDM methods and their applications as per the design stages. However, there is a lack of empirical evaluations of the different MCDM methods. Nowadays, the development of hybrid and modular methods is becoming significant increasingly. Therefore, in order to help decision makers for more suitable decision making, it is necessary to publish reviews on hybrid MCDM methods and approaches in future. Further, the paper identifies a need for further research into decision-making methods in global product development, in order to develop effective decision support tools for manufacturing companies involved in global product development.

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