

# Product Development using QFD, MCDM and the Combination of these Two Methods

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**Abstract.** Product development (PD) consists of several activities and one of early stage in PD is conceptual design stage which is the most crucial stage in developing a new product. Incorrect design concept and material selection in conceptual stage will lead to product failure and increase the cost. Nevertheless, if the conceptual design stage is properly executed important parameters such as the time and cost can be minimized. The quality of the product also has a tremendous improvement. This paper mainly discuss on tooling medium used for material selection and design concept. It covers Quality Function Deployment (QFD), Multi Criteria Decision Making (MCDM) including Analytical Network Process (ANP) and Analytical Hierarchy Process (AHP).

**Keywords:** Product development, Quality Function Deployment, Multi Criteria Decision Making, Analytical Network Process, Analytical Hierarchy Process

## 1. Introduction

Recently, companies are pressure to environmental issue, several aspects of companies' business and customers' satisfaction. Product development (PD) is introduced to interpret the customers' need into the product design and manufacturing. It involved serial activities consist of materials selection, product design, selection of the manufacturing process, prototyping, testing and validation and launch the product to the marketplace. Conceptual design stage is one of early stages in PD as it is the very important initial stage for development a new product. It is beneficial to minimize the cost and lead time; and maximize the quality of the product, flexibility and customers' satisfaction. There is an improved study in considering the precise decisions on the design concept and material selection concurrently at the early stage of development of product. Inappropriate decisions on design concept and material always lead to huge cost involvement and ultimately drive toward premature component or product failure [1]. The early consideration of conceptual design in PD process is very crucial to achieve cut down PD time, production costs, and quality defects. For example, previously, manufacturing process is conducted at the detail design stage, means until to this stage the critical issue regarding manufacturing process is not recognized and obviously it is too late to determine the constrains imposed by manufacturing process. It is very complicated to design the product without designing the materials at the early stage of design. The development of the new product can be



derived from the customers' needs and modification from the existing product [2]. The complex design under pressure of time and budget constrain thus the cost of error is the highest at this stage. Nowadays, the problem of sustainability including environmental pollution, global warming, energy consumption and etc. become a critical issue, hence engineers and designers must take into account the effects of their decisions on the environment and ecosystem. Sustainability at early stages of a product's life cycle needs to be implemented in industry. However, current PD activities in manufacturing industries are only concern more on quality, cost and energy consumption [3-4]. The selection of conceptual design, manufacturing process and material play an important role to minimize adverse impact on natural environmental systems toward achieving ecological sustainability [5]. Thus, the engineers and designers must introduce green criteria into the framework of selection criteria for conceptual design. To aid engineers and designers in determining and select the suitable design, manufacturing process and material, many methods have been developed in order to achieve company's specification, sustainability and satisfaction of customers' needs and expectations. Research by Genç [6] increased the theoretical understanding of the role of the environmental specialist in new PD and new product were success resulting of the positive influence on new product performance.

## **2. The function of Quality Function Deployment (QFD), Multi Criteria Decision Making (MCDM) and its combination in Product Development (PD)**

In achieving an effectively of sustainability it is essential to achieve improvements in economic, social and environmental aspects. In manufacturing or industries should take into account these three aspects of the sustainability as well as the investment cost. Designing a sustainable conceptual design is a critical process which can determine either the product is success or failed. Many tools are developed to evaluate design concept selection and compromise different effective factors including customer requirements, designer intentions and market desire [7]. In order to design effectively a sustainable product, a tool for environmentally conscious design process namely Quality Function Deployment (QFD) approach is used [8]. It is a customer-oriented design that was originated in Japan in 1972, which to improve quality in product development and ensure customer's voice is engaged throughout the product planning and design stages. QFD used to interpret customer requirement into engineering specifications for a product or service. In a new product development activity, design requirements and part characteristics are the major phases for QFD. The inaccurate design information can be characterized effectively by means of linguistic variables and fuzzy set theory [9]. The House of Quality (HoQ) tool that used by QFD, which is a matrix that provides a conceptual map for inter-functional planning and communication. In general, a QFD system is categorized into four inter-linked phases namely product planning, part deployment, process planning, and production planning phases [10][11]. HoQ indicates the relationship between CRs (what to do) and ECs (how to do it). The use of QFD has gained extensive international support for helping decision-makers in product planning and improvement [12].

Multi Criteria Decision Making (MCDM) is consisting of the Analytic Hierarchy Process (AHP) and Analytic Network Process (ANP) will be discussed in this study. AHP help in express the general decision operation by decomposing a complicated problem into a multilevel hierarchical structure of objective, criteria and alternatives. AHP performs a pair-wise comparison to develop relative importance of the variable in each level of the hierarchy and/or considers the alternatives in the lowest level of the hierarchy in order to make the best decision among alternatives. AHP is an effective decision making method especially when subjectivity happens and it is very suitable to solve problems where the decision criteria can be organized in a hierarchical way into sub-criteria. AHP is used to determine relative priorities on absolute scales from both discrete and continuous paired comparisons in multilevel hierarchic structures. The AHP method is based on three principles: first, structure of the model; second, comparative judgment of the criteria and/or alternatives; third, synthesis of the priorities. In AHP, firstly, a decision problem is constructed hierarchy. Initially, AHP breaks down a complex multi-criteria decision making problem into a hierarchy of interrelated decision elements

including criteria and decision alternatives. Secondly, the comparison of the criteria and/or the alternatives. The criteria are compared pair-wise according to their levels of influence and based on the specified criteria in the higher level for each level [13].

ANP is considered uncertainty among decision makers and also interdependency over the use of various criteria and alternatives. ANP requires the decision maker's opinion to carry out pair-wise comparisons. Fuzzy sets are integrated with the pair-wise comparison as an extension of ANP because the human assessment on qualitative attributes is always subjective and incorrect [9]. ANP evaluate a set of conceptual design alternatives to satisfy both customer satisfaction and engineering specifications [7]. The ANP is a generalized from the AHP. AHP involved with interaction and dependence of higher level elements in a hierarchy on lower level elements lead to difficulties in structured the decision hierarchically. The major advantage of ANP over AHP is ANP allows complex interrelationships among decision levels and attributes, while the AHP represents a framework with a unidirectional hierarchical AHP relationship [14]. As in the hierarchy, the importance of the criteria does not only determine the importance of alternative, but the importance of the alternative also determines the importance of the criteria. Means, the decision alternative in ANP can depend on criteria and each other as well as criteria can depend on alternatives and other criteria [15].

Several reason of using an AHP/ANP-based decision analysis approach in the present work firstly, both allow decision makers to analyze complex decision-making problems using a systematic approach that breaks down the main problem into simpler and affordable sub-problems. Secondly, if there are interdependencies among groups of elements (criteria and alternatives) ANP is recommended and thirdly the detailed analysis of priorities and interdependencies between clusters' elements forces the decision making to carefully reflect on his/her project priority approach and on the decision-making problem itself, which results in a better knowledge of the problem and a more reliable final decision [16].

Several researches have been conducted on QFD, MCDM and its combination in Product Development (PD). Research by Liu et al. [12] constructed an advanced QFD model based on fuzzy analytic network process (FANP) approach which proposed the interrelationship between and within the QFD components to take into systematically. The proposed method is aimed at expanding the current research scope from the product planning phase to the part deployment phase to provide product developers with more valuable information. Both customer requirements and the company's production demands will be used as the inputs for the QFD process to enhance the completeness and accuracy of the QFD analysis results. A QFD analysis process can be observed as a decision problem and thus can be formulated as an ANP model [10]. Another study by Lin et al. [11] proposed fuzzy quality function deployment (FQFD) model with interdependence relations between "What" (environmental production requirements aspects) and "How" (sustainable production indicators criteria) for original equipment manufacturing (OEM) firm in Taiwan. Combination of method of fuzzy set theory, ANP and QFD approach by explicitly describing the decision structure of sustainable production indicators by utilizing subjective judgments of evaluators based on this decision structure.

Zaim et al. [12] were studied on developing a pipe squeeze-off tool using two different approaches of crisp and fuzzy. First approach is the crisp approach where the ANP weighed QFD methodology was used to design and develop the product. In second approach, fuzzy logic was integrated within ANP weighed QFD. Both crisp- and fuzzy logic-based ANP weighed QFD methods are constructed after identifying quality characteristics that relate to the development of the new product then the results from both methods were compared and interpreted. The dependencies of customer needs characteristic in the QFD process are taken into account using the ANP method. In determining such weights of critical factors of designing the pipe squeeze-off tool, ANP method has been used to get more precise and effective results. The fuzzy logic was introduced for effective quantitative precision which improved the representation of criteria and therefore better result weights reflect on the customer requirements.

Lee et al. [17] conducted the research on product design process of backlight unit (BLU) in thin film transistor liquid crystal display (TFT-LCD) industry in Taiwan. Firstly, QFD is integrated with

the supermatrix approach of ANP and the fuzzy set theory to calculate the priorities of engineering characteristics with the consideration of the interrelationship of customer voice. Next, by considering the result from the QFD, multi-choice goal programming model is constructed. In short, framework of FANP, QFD and multi-choice goal programming is proposed to determine and select the most suitable engineering characterization such as material size, material selection, tube control, low-power IC design, power consumption control and quality control for product design. Even though there are many hybrid QFD models available, the models that applied ANP are rather limited. The result for fuzzy ANP-QFD shows that the design team should focus on material development, inverter control and quality control.

Due to pollution and global warming, environmental protection, Lin et al. [18] built an integrated new PD framework in developing the new products which to be implemented in a panel manufacturing firm for designing a green and low-carbon product namely a green and low carbon TFT-LCD panel. Lin et al. were proposed a three-stage framework that incorporates fuzzy interpretive structural modelling (FISM), FANP, QFD, fuzzy failure mode and effects analysis (FFMEA) and the goal programming (GP). First stage, to develop the product, customer attributes (CAs) and engineering characteristics (ECs) are collected through a comprehensive literature review and interviews with professionals, and (FISM) is applied in order to understand the relationships among these critical factors. In QFD, a HoQ is then built, and FANP is implemented to calculate the relative importance of ECs. Second stage, FFMEA is adopted to understand the potential failures of the ECs and to determine the importance of ECs with respect to risk control. In third stage, in order to select the most important of ECs and to consider result from FANP-QFD and FFMEA, GP model is built. As a result, it will contribute to the energy saving and waste reduction in the production process.

Hambali et al. [1] was recommended the use of AHP through utilizing Expert Choice software for solving design concept and materials selection was explored and then both decisions was verified by performing various scenarios of sensitivity analysis. Eight design concepts and six different types of composite materials of automotive bumper beam have been proposed. As the result from AHP and sensitivity analysis, the glass fibre epoxy and concept-6 are the most suitable decision for the material and design concept, respectively.

A study by Prasad et al. [19] proposed on QFD approach to overcome the problem during materials selection which relates with design requirement based on the properties of materials. To apply the QFD concept for material selection and a prototype is developed in Visual BASIC 6 software to automate the entire material selection decision making process. A study conducted by Mayyas et al. [20] on materials selection for vehicular structures, automotive Body-In-White (BiW) panels at the conceptual design by using AHP and QFD. Combinations of these tools give benefit as their abilities to rank the choices of level effectiveness orderly as to fulfill the functional objective. QFD was found to be a superior tool to decide on material selection for automotive body panel replacement for light weight BiW without scarifying the necessities of other customer needs as well as engineering requirements. As a comprehensive tool QFD was used in order to optimize the BiW designs based on a comprehensive methodology. However, AHP is a decision-making system which provides systematic selection method based on the selection criteria and sub-criteria; also it gives numerical priority vectors of the candidates. The AHP analysis reveals that steel is still the best choice for BiW among the other candidates. However, other candidates might work in some cases, but in trade-off cost or ease of manufacturing.

A study from Malekly et al. [21] combined the Technique for Order Performance by Similarity to Idea Solution (TOPSIS) and QFD for conceptual bridge design. TOPSIS is employed to select the best superstructure materials based on the weighted criteria achieved from the first phase. In this study the rating values regarding to each alternative and criteria throughout the phases are described in a fuzzy environment by means of linguistic variables. In order to illustrate the implementation process of the integrated methodology for bridge superstructure design, an expert team has been formed to collect and verify the expectations of the project. The results demonstrated that the proposed methodology could be successfully applied in the highway bridge projects as a useful tool to facilitate decision

making. Another study on construction field conducted by Akadiri et al. [22] on developing suitable systematic approaches and appropriate structured decision-making frameworks for sustainable building material selection. Current building materials selection methods did not managed to provide adequate solutions on sustainability principles and the process of prioritizing and assigning weights to relevant assessment criteria. Akadiri et al. proposed on a building material selection model based on the fuzzy extended analytical hierarchy process (FEAHP) techniques which used to rank and consign important weightings for the identified criteria. Sustainable assessment criteria (SAC) were identified based on sustainability triple bottom (TBL) approach. A questionnaire survey of building experts is conducted to assess the relative importance of the criteria and aggregate them into six independent assessment factors. As a result, FEAHP method clearly shows that qualitative criteria have an important impact on sustainability of building materials. However, in assessing composite priorities, Fuzzy AHP is a highly complex methodology and requires more numerical calculations than the traditional method and hence it increases the effort.

Increasing in awareness toward sustainable product, a research have done by Mansor et al. [23] on natural based fibre materials to substitute with synthetic based fibre in composites for automotive structural and semi structural applications. The selection of the most suitable natural fibre to be hybridized with glass fibre reinforced polymer composites for the design of a passenger vehicle centre lever parking brake component was utilized by using AHP method. Mansor et al. were provided thirteen (13) candidate natural based fibre materials for the hybridization process. As result, the kenaf bast fibre was selected to be hybridized with glass fibre reinforced polymer composites for the automotive component construction as it yields the highest scores and fulfil the design objective as well as performance requirement. Sensitivity analysis was also implemented to further validate the result gained from AHP and results show that kenaf bast fibre as the best candidate material in two out of three simulated scenarios. For the automotive parking brake lever design, Mansor et al. were provided six (6) major elements consist of performance, weight, standard, disposal, environment and cost and then categorized into eleven (11) sub-elements for more specific description which are strength, stiffness, density, parking brake lever testing standard, reuse and recyclability, safe for disposal, corrosion resistance, water absorption, raw material cost and manufacturing cost. From this study, author conclude that AHP method was demonstrated to be very effective to solve multi-criteria decision making problems during conceptual product design stage where it allow systematic and detailed rating values to be given between the comparing set of criteria and alternatives, however, it is more time consuming to obtain the final result especially when larger hierarchical structure is involved for their research.

Another research conducted by Mansor et al. [24] discussed on the conceptual design of kenaf fibre polymer composites automotive parking brake lever to substitute the existing steel based brake lever in order to reduce the weight while maintaining the strength and performance of the brake lever. The selection of the best concept design of the component based on the product design specifications to combine with the use of natural fibre polymer composites into the component design is utilised by using Theory of Inventive Problem Solving (TRIZ) contradiction matrix and 40 inventive principles solution tools in the early solution generation stage. The principle solution parameters for the specific design characteristics were later refined in details using the aid of morphological chart to systematically develop conceptual designs for the component. Five (5) novel design concepts of the component were proposed and AHP method was developed to select the best concept design for the polymer composite automotive parking brake lever component. In order to validate the design concept selection, subsequent sensitivity analysis performed later.

Ahmed Ali et al. [27] proposed AHP using the Expert Choice software tool for selecting the best natural fibre reinforced composite materials to replace synthetic materials. Then, sensitivity analysis was implemented with different scenarios for final result which priority to the environmental factors and sustainability. As result, the natural fibre composite material hemp and polypropylene showed the higher rank in the selection process and almost meet the requirements of industrial product design specification. These materials are recommended for automotive component manufacturers to

implement green technology. Expert Choice software, a multi-criteria decision support tool based on the AHP methodology was applied to determine the most suitable materials for materials selection. Primarily, a goal for the selection is defined and then the criteria and sub-criteria are listed. Next, the alternatives candidate materials are taken into consideration in the material selection. Once the hierarchy has been outlined and the criteria and sub-criteria are identified for the selection, the important stage was to identify the candidate materials. Authors maximized some criteria such as mechanical properties, and biodegradability and minimized some criteria physical property, material cost and environmental risk. Finally, sensitivity analysis is performed to further validate on the result gained. The summarization of this study is shown in Table 1.

**Table 1. Literature survey for MCDM tool and QFD.**

Author	Year	MCDM tool	Secondary method	Specific areas
Liu et al.	2011	FANP	QFD	Product planning
Lin et al.	2010	ANP	FQFD	Environmental production requirement
Zaim et al.	2014	ANP	QFD	Product development
Lee et al.	2010	ANP	QFD	Product design selection
Lin et al.	2015	FANP	QFD, FISM FEAEA, GP	Product development
Hambali et al.	2011	AHP	Expert Choice software	Design concept selection and materials selection
Prasad et al.	2013	-	QFD, Visual BASIC 6	Materials selection
Mayyas et al.	2011	AHP	QFD	Materials selection
Malekly et al.	2010	-	QFD, TOPSIS	Design concept
Akadiri et al.	2013	FEAHP	sustainability triple bottom (TBL) approach	Material selection
Mansor et al.	2013	AHP	Sensitivity analysis	Materials selection
Mansor et al.	2014	AHP	TRIZ, morphological chart	Concept design
Ahmed Ali et al.	2015	AHP	Expert Choice software, sensitivity analysis	Materials selection

### 3. Conclusions

Product Development (PD) is essential in developing a new product as well as improving the existing product. PD most crucial stage is the conceptual design. In general conceptual design is comprises of manufacturing process, design concept and material selection. Design concept provides several designs on the product hence helps in summarizing as well as following the customer needs. During this concept design, material selection can be made simultaneously depending on the requirements. Quality Functional Deployment (QFD) is a tool to interpret the customer voice into engineering specifications. Whereas Multi Criteria Decision Making (MCDM) enable designers to decide on the best design and material for the product. Both QFD and MCDM implementation ensure the successfulness of product development.

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