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Fusing Multi-Attribute Decision Models for Decision Making to Achieve Optimal Product Design

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Abstract. Manufacturers need to select the best design from alternative design concepts in order to meet up with the demand of customers and have a larger share of the competitive market that is flooded with multifarious designs. Evaluation of conceptual design alternatives can be modelled as a Multi-Criteria Decision Making (MCDM) process because it includes conflicting design features with different sub features. Hybridization of Multi Attribute Decision Making (MADM) models has been applied in various field of management, science and engineering in order to have a robust decision-making process but the extension of these hybridized MADM models to decision making in engineering design still requires attention. In this article, an integrated MADM model comprising of Fuzzy Analytic Hierarchy Process (FAHP), Fuzzy Pugh Matrix and Fuzzy VIKOR was developed and applied to evaluate conceptual designs of liquid spraying machine. The fuzzy AHP was used to determine weights of the design features and sub features by virtue of its fuzzified comparison matrix and synthetic extent evaluation. The fuzzy Pugh matrix provides a methodical structure for determining performance using all the design alternatives as basis and obtaining aggregates for the designs using the weights of the sub features. The fuzzy VIKOR generates the decision matrix from the aggregates of the fuzzified Pugh matrices and determine the best design concept from the defuzzified performance index. At the end, the optimal design concept is determined for the liquid spraying machine.

Keywords: Hybridized Multi-Attribute Decision-making, Fuzzy AHP, Fuzzified Pugh Matrix, Fuzzy VIKOR, Optimal conceptual design.

1. Introduction

The desire of manufacturers to have a sustainable product with prolonged and useful life cycle can be achieved through a comprehensive and systematic decision process in the conceptual design phase [1, 2]. Selection of best design concept from an alternative set of designs is an important stage in engineering design process that requires attention because the performance of the final design throughout its life cycle depends on some features that may have been considered during the decision process [3, 4]. In practice, design concepts are developed based on user's requirements and underlying design principles. However, during

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the concept design process, the designers are constrained to add design features that will satisfy the requirements or demands of the end users [5, 6]. Since the demands of end users are multifarious, hence there is no particular design concept that tends to satisfy all the expected design features. In view of this, design engineers are left with no option than to have different design concepts. Since it easier for the managerial team to harness all the required information that is obtainable form the market, then the next task of the design engineer is to analyze the design requirements and allot same to different design features [7, 8]. To further simplify the design process, the design engineers usually assign similar end user's requirements to various sub features that can be traced to a particular design feature. In essence, the design engineers have alternative design concepts with numerous sub features that have been categorized under identified design features [9, 10]. At this stage the task of choosing the best design concept requires a detailed evaluation of the design features and their sub features because this dictates to the manufacturer the right product to choose in order to have a share of the competitive market flooded with diverse designs [11-13]. It is worthwhile to know at this stage that these design features and sub features have various units and dimensions which makes it difficult to apportion crisp values to them in the decision process. Hence, there is a need to employ a robust decision process in order to avoid any form of ambiguity in the process of selecting the best design. Considering the fact that the manufacturer wants to provide a product that will capture a reasonable share of the market, it becomes imperative to carry out a decision-making process at the conceptual phase of the design. This leads to modelling the decision process as a multi criteria decision model in order to achieve the selection of the optimal design concept.

In the past, when the goal of the manufacturer is achieving mass production, selection of best design concept has been done based on the decisions of design experts by selecting a design concept having the required and cogent design features [14, 15]. However, in recent times when the goal has shifted from mass production to personalized and/or mass customization of products, selection of best design concept of products requires a systematic process that involves the use of extensive decision tools [16, 17]. Decision making in engineering design can be modelled as a Multi-Criteria Decision Analysis (MCDA) where all the design features and sub features can be apportioned weights and the relative importance of the design features in the design alternatives are evaluated using appropriate MCDA tools [2, 18, 19]. Basically, MCDA can be broadly classified into Multi-Attribute Decision making (MADM) and Multi-Objective Decision Making (MODM) [5, 20, 21]. The MADM deals with the challenges of making a choice from a set of alternatives within a discrete solution space. It utilizes approaches such as Analytic Hierarchy Process (AHP), Weighted Sum Model (WSM), Weighted Average model (WA), Analytic Network Process (ANP), VIseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) and Elimination and Choice Translating Reality (ELECTRE) among others [4]. Considering the ELECTRE model, developed by Bernard Roy [22], it is an outranking method applied to different difficulties encountered within a specific problem. There are several versions of the model as a result of deviation in decision problem from choice of identifying a single alternative to development of ranking sets of alternatives considering the imprecision in performances of the alternatives relative to several criteria [23]. The MODM comes to play when there are no discrete sets of explicitly defined alternatives. MODM provides search for an infinite set solution in a continuous space and it usually emerges at two stages which are implementation of higher-level strategic decisions at a more detailed operational level and generation of explicit set of alternatives for more detailed evaluation before a final decision is reached.

Examples of methods applied in MODM are linear programming approaches, Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and Goal Programming (GP) [24-26].

In recent times, attempts have been made to improve decision making by hybridizing MADM models to solve real life problems. Some of these applications includes supplier selection [27], auxiliary systems of ship main engines [28], green supply chain implementation in the textile industry [29], gas turbine component selection [30], healthcare decision making [31], combination of materials selection [32] and Steam boilers [33]. However, extending the application of hybridized models to ranking of design concepts is still a decision task of interest because only few article has addressed such approach [34, 35]. The choice of models to select for integration depends on the computational procedure of the models and nature of the features used in the decision process. Best results can be obtained by harnessing the advantages of the MADM models to be hybridized. In essence, the aim of this article is to investigate the hybridization of MADM models to make decision on the best design concept considering several conceptual design alternatives. The investigation will address the challenges of determining optimal design concept from a set of alternatives by providing a repeatable method that can be applied for subsequent designs. This implies that, research questions regarding which robust decision model can be employed for assessing alternative conceptual designs in order to identify optimal design concept will be addressed in as much as the design engineer has identified the design features and sub features required for characterizing the optimal or best design.

Further, on the aspect of repeatability of the hybridized model, the study will provide a detailed framework that represents the procedure for application of the model in order to ensure that it can be applied by other design engineer in making decision for other products or design alternatives. Although this depends on establishment of design features and sub features of subsequent design that will be used with the hybridized model. The choice of design features and sub features to be applied in the decision process has always been a challenge in the modelling of best design concept selection as a multi criteria decision model. The generic design features which is usually embedded in design for X principles finds usefulness in the decision process but it is usually faced with the challenges of addressing some peculiar features and requirements of the design, particularly considering features that has to do with functionality or expected performance of the design. In essence, the example that will be proposed in this article will have design features which are peculiar to the design under consideration which can be added to the generic design features in order to have a robust decision process.

To this end, this article proposes an integration of Fuzzy Analytic Hierarchy Process (FAHP), fuzzified Pugh matrix (FPM) and fuzzy VIKOR (FVIKOR) for evaluating design concepts using a trapezoidal fuzzy number. Although AHP, Pugh matrix and VIKOR are methods that can be used separately for decision making but hybridizing these methods will harness their computational strength. For instance, the AHP is good in the aspect of pairwise comparison which usually provides priority for alternatives or criteria under comparison. The Pugh matrix is a good decision tool to consider when it is required to compare all alternatives relative to each other and also considering the weights of the design features or sub features. Also, the VIKOR method is known for its computational integrity in terms of the worst and best values and separation measures in order to arrive at a performance index for the alternatives. Hence, the main reason for hybridizing these methods in this article is to harvest their computational strengths in order to have a robust decision-making process. The primary reason for using trapezoidal fuzzy numbers (TrFN) can be stated as its intuitive and efficient computational representation. They are appropriate for quantifying the vague information about most decision problems, particularly in design analysis because the design features cannot be quantified with the same dimensions or units. The novelty of this article is integrating the computational strength of Fuzzy AHP in terms of Fuzzy Synthetic Extent (FSE) from fuzzified pairwise comparison matrix to obtain weights for the design features and sub features and then using these weights to aggregate the Fuzzified Pugh (FPUGH) matrices developed using all the alternatives as basis. The obtained aggregates are used to generate the decision matrix using the computational strength of Fuzzy VIKOR (FVIKOR) in terms of the distances of the design alternatives from fuzzy best and worst values, separation measures and performance index computations.

2. Methodology

A framework for the hybridized model is presented in Figure 1. This framework is necessary for highlighting the procedure required for applying the hybridized model to other product design. In the framework, stages involving each of the hybridized MADM models are represented in coloured textbox in order simplify the application process. To further simplify the repeatability of the hybridized model for other designs, attempts have been made to include the equation numbers of the mathematical models that will applied at each stage of the process. To begin with, Fuzzified Pairwise Comparison Matrices (FPCM) are needed for the design features and their various sub features. These matrices are obtained from allocation of TrFN by design experts. The aggregates from the comparison matrices of the sub features that are obtained from Fuzzy Synthetic Extent (FSE) values are required as weights for the fuzzified Pugh matrices. These Pugh matrices are developed for all design features using the design concepts as basis. The aggregated TrFN from the Pugh matrices of the design features formulates elements of the fuzzy decision matrix. Also, the decision matrix is weighted by the aggregate of the comparison matrix of the design features. The fuzzy best and worst values are obtained from the decision matrix. The separation measures and performance index of the design concepts are obtained and defuzzified in order to achieve ranking of the design concepts. The linguistic terms and the distribution for the trapezoidal fuzzy number is presented in Table 1.

Table 1. Trapezoidal Fuzzy Numbers and Linguistic terms adopted for FAHP and FPUGH

Fuzzy AHP		
Linguistic Terms for Relative Significance of design features and sub features in the Design	Trapezoidal Fuzzy Scale Membership Function	Crisp Value of Ranking/ Rating
Equally Important	1 1 1 1	1
Weakly Important	1 3/2 2 5/2	2
Essentially Important	7/4 9/4 11/4 13/4	3
Highly Important	5/2 3 7/2 4	4
Very highly Important	13/4 15/4 17/4 19/4	5
Fuzzy PUGH		

Linguistic Terms for comparing Design concepts considering the sub features Trapezoidal Fuzzy Scale Membership Function		Crisp Value of Ranking/ Rating
Much Better	13/4 15/4 17/4 19/4	1
Better	5/2 3 7/2 4	2
Same	1 1 1 1	3
Worse	7/4 9/4 11/4 13/4	4
Much Worse	1 3/2 2 5/2	5

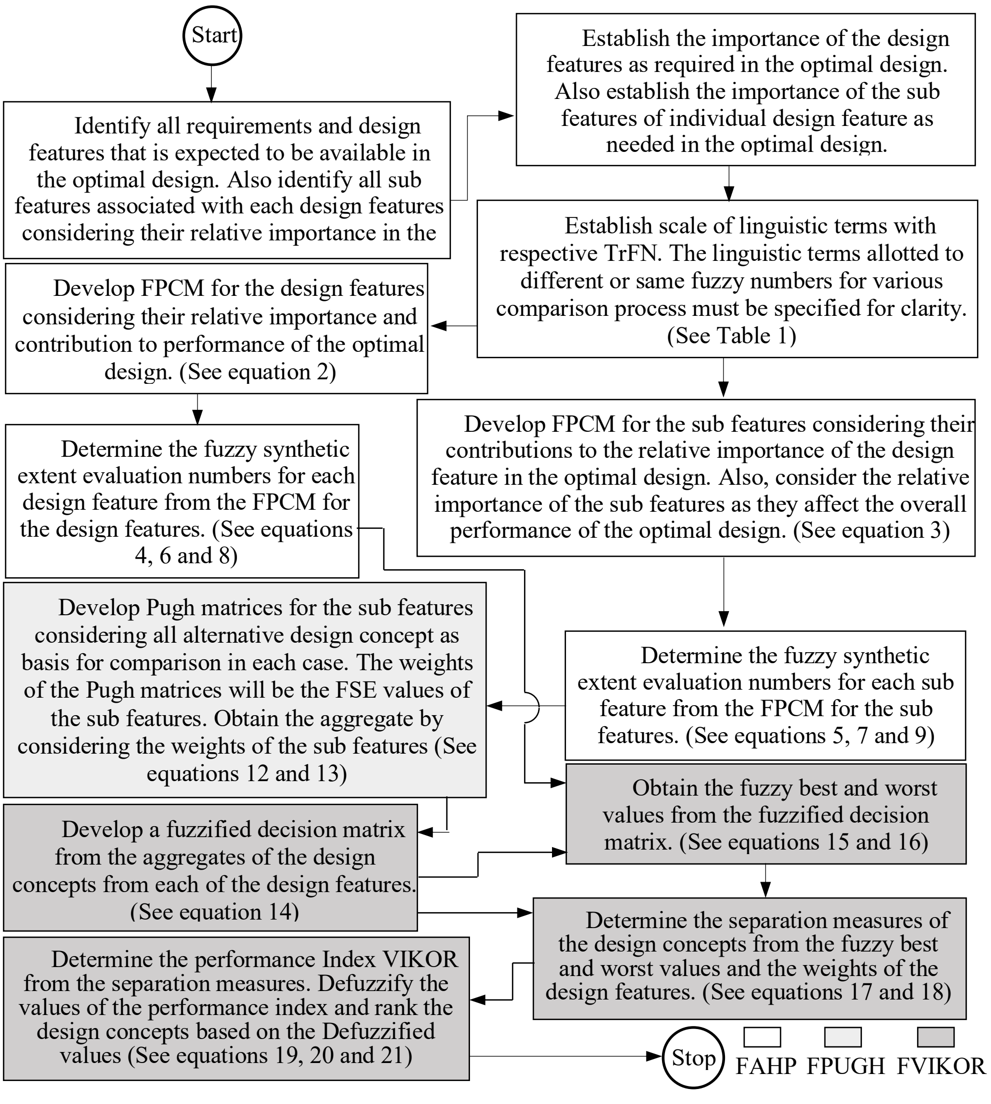

Figure 1. Framework for Hybridized Model

2.1. Fuzzy AHP

In order to simplify the analysis, consider *n* number of design concepts $\left(D_{Cn}\right)$ which represents alternatives from which an optimal design will be chosen using *m* number of design features $\left(D_{Fm}\right)$ that are characterized by *k* number of sub features $\left(S_{Fk}\right)$. In order to quantify the relative importance of the design features and sub features in the optimal design, it is necessary to assign trapezoidal fuzzy numbers (A_i) to the elements of the pairwise comparison matrices using linguistic terms presented in Table 1. The membership function '$\mu_A(y)$' of the trapezoidal fuzzy number (TrFN) $A=\{a,\ b,\ c,\ d\}$ can be expressed as; [36, 37]

$$\mu_A(y)=\begin{cases}\dfrac{y-a}{b-a} & y\in[a,\ b]\\ 1 & y\in[b,\ c]\\ \dfrac{d-y}{d-c} & y\in[c,\ d]\\ 0 & \text{Otherwise}\end{cases} \tag{1}$$

Where $a\le b\le c\le d$. Judgement matrices of the form $\tilde{B}=\left\{\tilde{b}_{gi}^{j}\right\}$ can be developed for pairwise comparison matrices of the design features and sub features. Where *j* and *i* represents columns and rows respectively. Since there are *m* number of design features with *k* number of different sub-features it follows that the element in the rows of the judgement matrices for the design features and sub features will be represented with *m* and *k* respectively. In essence, judgement matrix for the design features can be expressed as shown in equation 2. Also, since there are various sub features under each of the design features, judgement matrices of the sub features can also be described as presented in equation 3 [38, 39].

$$\tilde{D}_F=\begin{bmatrix}\tilde{d}_{f1}^{1} & \tilde{d}_{f1}^{2} & \dots\dots\dots\; \tilde{d}_{f1}^{q}\\ \tilde{d}_{f2}^{1} & \tilde{d}_{f2}^{2} & \dots\dots\dots\; \tilde{d}_{f2}^{q}\\ \vdots & \vdots & \vdots\\ \tilde{d}_{fm}^{1} & \tilde{d}_{fm}^{1} & \dots\dots\dots\; \tilde{d}_{fm}^{q}\end{bmatrix} \tag{2}$$

Since *j* and *i* represents columns and rows respectively then it follows that *i=1, 2, 3…m; j=1, 2, 3…q* such that $\tilde{d}_{f1}^{q}=\begin{bmatrix}1 & 1 & 1 & 1\end{bmatrix}$ when *i = j*.

$$\tilde{S}_{F_k}\Big|_m = \begin{bmatrix} \tilde{s}_{f1}^{1} & \tilde{s}_{f1}^{2} & \dots\dots\dots & \tilde{s}_{f1}^{p} \\ \tilde{s}_{f2}^{1} & \tilde{s}_{f2}^{2} & \dots\dots\dots & \tilde{s}_{f2}^{p} \\ \vdots & \vdots & & \vdots \\ \tilde{s}_{fk}^{1} & \tilde{s}_{fk}^{2} & \dots\dots\dots & \tilde{s}_{fk}^{p} \end{bmatrix} \tag{3}$$

Similarly, since j and i represents columns and rows respectively then it follows that $i=1, 2, 3\ldots k; j=1, 2, 3\ldots p$ such that $\tilde{s}_{fk}^{p} = [1\ \ 1\ \ 1\ \ 1]$ when $i = j$. Where $\tilde{S}_{F_k}\Big|_m$ represents k set of sub features corresponding to design feature m and $\tilde{s}_{fk}^{j}$ is the TrFN for k^{th} sub feature corresponding to j^{th} column. Similarly, from equation 2, $\tilde{d}_{fm}^{j}$ is the TrFN for m^{th} design feature corresponding to j^{th} column. The fuzzy synthetic extent (F_{se}) will be obtained for all the pairwise comparison matrices that have been developed for all the design features and the sub features. In essence, the weights of the relative importance of the design features (D_{Fm}^{w}) and sub features ($S_{F_k}^{w}$) will be obtained from the value of the fuzzy synthetic extent which can be defined for the design features "$[F_{se}]_{\tilde{D}_F}$" and sub features "$[F_{se}]_{\tilde{S}_{Fk}}$" as presented in equations 4 and 5. This implies that the (F_{se}) for the design features is obtainable from equation 4 following the pairwise comparison matrix in equation 2 and the (F_{se}) for the sub features is obtainable from equation 5 following the pairwise comparison matrix in equation 3 [40, 41];

$$D_{Fm}^{w} = [F_{se}]_{\tilde{D}_F} = \sum_{j=1}^{q} d_{fm}^{j} \otimes \left[\sum_{i=1}^{m}\sum_{j=1}^{q} d_{fm}^{j} \right]^{-1} \tag{4}$$

$$S_{F_k}^{w} = [F_{se}]_{\tilde{S}_{Fk}} = \sum_{j=1}^{p} s_{fk}^{j} \otimes \left[\sum_{i=1}^{k}\sum_{j=1}^{p} s_{fk}^{j} \right]^{-1} \tag{5}$$

Considering the fact that equations 4 and 5 are crucial for determination of weights for the design features and sub features, it is necessary to provide an example of their application. In order to achieve this, consider substituting the membership function of the TrFN in equation 1 into equations 2 and 3, this will further analyze the elements of the pairwise comparison matrices of the design features and sub features into simpler form as presented in equations 6 and 7 respectively. This implies that equations 4 and 5 will be applied to equations 6 and 7 respectively.

$$\tilde{D}_F = \begin{bmatrix} a_{11}, b_{11}, c_{11}, d_{11} & a_{21}, b_{21}, c_{21}, d_{21} & \text{..........} \; a_{q1}, b_{q1}, c_{q1}, d_{q1} \\ a_{12}, b_{12}, c_{12}, d_{12} & a_{22}, b_{22}, c_{22}, d_{22} & \text{..........} \; a_{q2}, b_{q2}, c_{q2}, d_{q2} \\ \vdots & \vdots & \vdots \\ a_{1m}, b_{1m}, c_{1m}, d_{1m} & a_{2m}, b_{2m}, c_{2m}, d_{2m} & \text{..........} \; a_{qm}, b_{qm}, c_{qm}, d_{qm} \end{bmatrix} \quad (6)$$

Where;

$$a_{11}, b_{11}, c_{11}, d_{11} = a_{22}, b_{22}, c_{22}, d_{22} = a_{qm}, b_{qm}, c_{qm}, d_{qm} = [1, 1, 1, 1] \;\; \forall\, q = m$$

$$\tilde{S}_{F_k}\Big|_m = \begin{bmatrix} a_{11}, b_{11}, c_{11}, d_{11} & a_{21}, b_{21}, c_{21}, d_{21} & \text{..........} \; a_{p1}, b_{p1}, c_{p1}, d_{p1} \\ a_{12}, b_{12}, c_{12}, d_{12} & a_{22}, b_{22}, c_{22}, d_{22} & \text{..........} \; a_{p2}, b_{p2}, c_{p2}, d_{p2} \\ \vdots & \vdots & \vdots \\ a_{1k}, b_{1k}, c_{1k}, d_{1k} & a_{2k}, b_{2k}, c_{2k}, d_{2k} & \text{..........} \; a_{pk}, b_{pk}, c_{pk}, d_{pk} \end{bmatrix} \quad (7)$$

Where

$$a_{11}, b_{11}, c_{11}, d_{11} = a_{22}, b_{22}, c_{22}, d_{22} = a_{pk}, b_{pk}, c_{pk}, d_{pk} = [1, 1, 1, 1] \;\; \forall\, p = k$$

Applying equation 4 to equation 6 we have;

$$D_{F_1}^{w} = \left[a_{11} + a_{21} + ...a_{q1}\right], \left[b_{11} + b_{21} + ...b_{q1}\right], \left[c_{11} + c_{21} + ...c_{q1}\right], \left[d_{11} + d_{21} + ...d_{q1}\right] \otimes$$
$$\left[\begin{bmatrix} a_{11} + a_{12} + ...a_{1m} + \\ a_{21} + a_{22} + ...a_{2m} + \\ a_{q1} + a_{q2} + ...a_{qm} \end{bmatrix}, \begin{bmatrix} b_{11} + b_{12} + ...b_{1m} + \\ b_{21} + b_{22} + ...b_{2m} + \\ b_{q1} + b_{q2} + ...b_{qm} \end{bmatrix}, \begin{bmatrix} c_{11} + c_{12} + ...c_{1m} + \\ c_{21} + c_{22} + ...c_{2m} + \\ c_{q1} + c_{q2} + ...c_{qm} \end{bmatrix}, \begin{bmatrix} d_{11} + d_{12} + ...d_{1m} + \\ d_{21} + d_{22} + ...d_{2m} + \\ d_{q1} + d_{q2} + ...d_{qm} \end{bmatrix}\right]^{-1} \quad (8)$$

In the same way, applying equation 5 to equation 7 will yield;

$$S_{F_1}^{w} = \left[a_{11} + a_{21} + ...a_{p1}\right], \left[b_{11} + b_{21} + ...b_{p1}\right], \left[c_{11} + c_{21} + ...c_{p1}\right], \left[d_{11} + d_{21} + ...d_{p1}\right] \otimes$$
$$\left[\begin{bmatrix} a_{11} + a_{12} + ...a_{1k} + \\ a_{21} + a_{22} + ...a_{2k} + \\ a_{p1} + a_{p2} + ...a_{pk} \end{bmatrix}, \begin{bmatrix} b_{11} + b_{12} + ...b_{1k} + \\ b_{21} + b_{22} + ...b_{2k} + \\ b_{p1} + b_{p2} + ...b_{pk} \end{bmatrix}, \begin{bmatrix} c_{11} + c_{12} + ...c_{1k} + \\ c_{21} + c_{22} + ...c_{2k} + \\ c_{p1} + c_{p2} + ...c_{pk} \end{bmatrix}, \begin{bmatrix} d_{11} + d_{12} + ...d_{1k} + \\ d_{21} + d_{22} + ...d_{2k} + \\ d_{p1} + d_{p2} + ...d_{pk} \end{bmatrix}\right]^{-1} \quad (9)$$

In essence, equations 8 and 9 will provide the fuzzy synthetic extents for first design feature and sub features respectively. Following the same pattern, the fuzzy synthetic extents for the second design feature or the second sub feature a design feature can also be obtained as presented in equations 10 and 11 respectively.

$$D_{F_2}^{w}=\left[a_{12}+a_{22}+...a_{q2}\right],\ \left[b_{12}+b_{22}+...b_{q2}\right],\ \left[c_{12}+c_{22}+...c_{q2}\right],\ \left[d_{12}+d_{22}+...d_{q2}\right]\otimes$$

$$\left[\begin{bmatrix}a_{11}+a_{12}+...a_{1m}+\\a_{21}+a_{22}+...a_{2m}+\\a_{q1}+a_{q2}+...a_{qm}\end{bmatrix},\begin{bmatrix}b_{11}+b_{12}+...b_{1m}+\\b_{21}+b_{22}+...b_{2m}+\\b_{q1}+b_{q2}+...b_{qm}\end{bmatrix},\begin{bmatrix}c_{11}+c_{12}+...c_{1m}+\\c_{21}+c_{22}+...c_{2m}+\\c_{q1}+c_{q2}+...c_{qm}\end{bmatrix},\begin{bmatrix}d_{11}+d_{12}+...d_{1m}+\\d_{21}+d_{22}+...d_{2m}+\\d_{q1}+d_{q2}+...d_{qm}\end{bmatrix}\right]^{-1} \tag{10}$$

$$S_{F_2}^{w}=\left[a_{12}+a_{22}+...a_{p2}\right],\ \left[b_{12}+b_{22}+...b_{p2}\right],\ \left[c_{12}+c_{22}+...c_{p2}\right],\ \left[d_{12}+d_{22}+...d_{p2}\right]\otimes$$

$$\left[\begin{bmatrix}a_{11}+a_{12}+...a_{1k}+\\a_{21}+a_{22}+...a_{2k}+\\a_{p1}+a_{p2}+...a_{pk}\end{bmatrix},\begin{bmatrix}b_{11}+b_{12}+...b_{1k}+\\b_{21}+b_{22}+...b_{2k}+\\b_{p1}+b_{p2}+...b_{pk}\end{bmatrix},\begin{bmatrix}c_{11}+c_{12}+...c_{1k}+\\c_{21}+c_{22}+...c_{2k}+\\c_{p1}+c_{p2}+...c_{pk}\end{bmatrix},\begin{bmatrix}d_{11}+d_{12}+...d_{1k}+\\d_{21}+d_{22}+...d_{2k}+\\d_{p1}+d_{p2}+...d_{pk}\end{bmatrix}\right]^{-1} \tag{11}$$

2.2. Fuzzified Pugh Matrix

The fuzzy Pugh creates judgement matrices of the form $\tilde{P}=\left\{\tilde{p}_{gi}^{j}\right\}$ for all the sub features under a particular design feature using all the design concepts as baselines [42, 43]. The judgement matrices are aggregated with the weights of the sub features. It can be expressed as presented in equation 12. It is worthwhile to know that the aggregates in equation 12 will be obtained after the Pugh matrices have been repeated using all the design concepts as basis. In essence it can be deduced that for a design concept under consideration as basis then $p_{g1}^{1}=p_{g2}^{1}=......=p_{gi}^{1}=1\ \ 1\ \ 1\ \ 1$. The aggregate of each design concept can be obtained from equation 13.

$$\begin{array}{llccccccc}
 & & \multicolumn{7}{c}{\text{Design Alternatives}} \\
 & & D_{C_1} & D_{C_2} & \cdots & \cdots & \cdots & D_{Cn} \\
 & S_{F_1}^{w} & p_{g1}^{1} & p_{g1}^{2} & \cdots & \cdots & \cdots & p_{g1}^{j} \\
 & S_{F_2}^{w} & p_{g2}^{1} & p_{g2}^{2} & \cdots & \cdots & \cdots & p_{g2}^{j} \\
\text{Sub Features} & \vdots & \vdots & \vdots & \cdots & \cdots & \cdots & \vdots \\
 & \vdots & \vdots & \vdots & \cdots & \cdots & \cdots & \vdots \\
 & S_{F_k}^{w} & p_{gi}^{1} & p_{gi}^{2} & \cdots & \cdots & \cdots & p_{gi}^{j} \\
\text{Aggregate} & \left[D_{Cn}\right]_{agg} & \cdots & \cdots & \cdots & \cdots & \cdots & \cdots
\end{array} \tag{12}$$

$$\left[D_{Cn}\right]_{agg}\Big|_j = \sum_{i=1}^{i=i}\left(S_{F_k}^{w} * p_{gi}^{j}\right) \tag{13}$$

2.3. Fuzzy VIKOR

A decision matrix is developed from all the aggregates of the Pugh matrices of the design features. The decision matrix is weighted by the relative importance of the design features (D_{Fm}^{w}) obtained from equation 4. The matrix can be represented by equation 14;

$$\begin{array}{c|cccccc}
 & D_{C_1} & D_{C_2} & D_{C_3} & \cdots & D_{Cn} \\
\hline
D_{F_1}^{w} & \left[D_{C_1}\right]_{agg}\Big|_1^1 & \left[D_{C_2}\right]_{agg}\Big|_1^2 & \left[D_{C_3}\right]_{agg}\Big|_1^3 & \cdots & \left[D_{Cn}\right]_{agg}\Big|_1^n \\
D_{F_2}^{w} & \left[D_{C_1}\right]_{agg}\Big|_2^1 & \left[D_{C_2}\right]_{agg}\Big|_2^2 & \left[D_{C_3}\right]_{agg}\Big|_2^3 & \cdots & \left[D_{Cn}\right]_{agg}\Big|_2^n \\
D_{F_3}^{w} & \left[D_{C_1}\right]_{agg}\Big|_3^1 & \left[D_{C_2}\right]_{agg}\Big|_3^2 & \left[D_{C_3}\right]_{agg}\Big|_3^3 & \cdots & \left[D_{Cn}\right]_{agg}\Big|_3^n \\
\vdots & \vdots & \vdots & \vdots & \cdots & \vdots \\
D_{F_m}^{w} & \left[D_{C_1}\right]_{agg}\Big|_m^1 & \left[D_{C_2}\right]_{agg}\Big|_m^2 & \left[D_{C_3}\right]_{agg}\Big|_m^3 & \cdots & \left[D_{Cn}\right]_{agg}\Big|_m^n
\end{array} \tag{14}$$

The fuzzy best ($\tilde{f}_b^{*}$) and worst ($\tilde{f}_w^{-}$) values can be obtained from the decision matrix for all the design features as expressed in equations 15 and 16 respectively [44, 45]. Further, the separation measures which comprises of the maximum group utility values (S_n) and the minimum individual regret values of the opponent design alternatives (R_n) can also be obtained from equations 17 and 18 respectively [46, 47]. The performance index VIKOR (Q_n) is also obtained in terms of fuzzy number from the minimum and maximum values of the group utility and individual regret of the opponent design alternative as presented in equation 19 [48-50].

$$\tilde{f}_b^{*}\Big|_m = \underset{n}{\mathrm{Max}}\left[D_{Cn}\right]_{agg}\Big|_m^n \tag{15}$$

$$\tilde{f}_w^{-}\Big|_m = \underset{n}{\mathrm{Min}}\left[D_{Cn}\right]_{agg}\Big|_m^n \tag{16}$$

$$S_n = \sum_{m=1}^{m=m}\left[\left(D_{F_m}^{w}\right)*\frac{\left(\tilde{f}_b^*\Big|_m - [D_{Cn}]_{agg}\Big|_m^n\right)}{\left(\tilde{f}_b^*\Big|_m - \tilde{f}_w^-\Big|_m\right)}\right] \tag{17}$$

$$R_n = \underset{m}{\text{Max}}\left[\left(D_{F_m}^{w}\right)*\frac{\left(\tilde{f}_b^*\Big|_m - [D_{Cn}]_{agg}\Big|_m^n\right)}{\left(\tilde{f}_b^*\Big|_m - \tilde{f}_w^-\Big|_m\right)}\right] \tag{18}$$

$$Q_n = \upsilon\left[\frac{S_n - S^*}{S^- - S^*}\right] + (1-\upsilon)\left[\frac{R_n - R^*}{R^- - R^*}\right] \tag{19}$$

Where $S^* = \underset{n}{\text{Min}}\ S_n$; $S^- = \underset{n}{\text{Max}}\ S_n$; $R^* = \underset{n}{\text{Min}}\ R_n$; $R^- = \underset{n}{\text{Max}}\ R_n$. Also υ and $1-\upsilon$ represents the weight for the strategy of maximum group utility and the weight of the individual regret of an opponent strategy. υ usually assumed to be 0.5 [45, 46]. The value of Q_n is defuzzified (Q_n^{dfu}) in order to obtain best nonfuzzy performance value for the design alternatives. The performance index VIKOR is defuzzified in equation 20 from the graded mean integrated method considering the trapezoidal fuzzy number described in equation 1 [39]. The optimal design concept (D_{cn}^{opt}) is the minimum of the best nonfuzzy performance value of Q_n as presented in equation 21. Other concepts are also ranked in the same order such that the design concept with the highest defuzzified value is taken as the least.

$$Q_n^{dfu} = \frac{1}{6}[a + 2b + 2c + d] \tag{20}$$

$$D_{cn}^{opt} = \underset{n}{\text{Min}}\left\{Q_n^{dfu}\right\} \tag{21}$$

3. Application

Four conceptual design of liquid spraying machine are considered as design alternatives with eight design features (Assembly and Disassembly (AD), Manufacturing (MA), Functionality (FU), Reliability (R), Maintainability (MN), Life Cycle Cost (LC), Serviceability (SE), Operation (OP) and Flexibility (FT)). These design features have different sub features as presented in Figure 2. An example of the fuzzified pairwise comparison matrix is developed in excel spread sheet for the design features as shown in Table 2. Further, Tables *A* to *H* in APPENDIX I presents the pairwise comparison matrices for the sub features considering each of the design features. However, the FSE results obtained for the sub features from these matrices are presented in Table 3. Fuzzified Pugh matrices are developed for all the design features using the design alternatives as basis as presented in Tables *I* to *P* in APPENDIX II. Aggregates are obtained from the weights of the sub features and the Pugh matrices representing the ranking of the availability of sub features in the component parts of the alternative design.

Table 2. Pairwise Comparison Matrix for the Design Features

Design Features							
MA	***AD***	***FU***	***LC***	***MN***	***RE***	***OP***	***FT***
$1\ 1\ 1\ 1$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$
$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$1\ 1\ 1\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$
$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$1\ 1\ 1\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$
$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$1\ 1\ 1\ 1$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$
$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$1\ 1\ 1\ 1$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$
$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$1\ 1\ 1\ 1$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$
$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$1\ 1\ 1\ 1$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$
$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$1\ 1\ 1\ 1$
FSEs							
MA	***AD***	***FU***	***LC***	***MN***	***RE***	***OP***	***FT***
$\frac{2}{19}\ \frac{6}{41}\ \frac{18}{89}\ \frac{2}{7}$	$\frac{5}{46}\ \frac{3}{19}\ \frac{2}{9}\ \frac{6}{19}$	$\frac{3}{29}\ \frac{14}{95}\ \frac{13}{63}\ \frac{16}{55}$	$\frac{3}{55}\ \frac{3}{37}\ \frac{2}{17}\ \frac{9}{52}$	$\frac{2}{33}\ \frac{3}{34}\ \frac{11}{87}\ \frac{9}{49}$	$\frac{5}{91}\ \frac{4}{49}\ \frac{7}{59}\ \frac{1}{8}$	$\frac{5}{73}\ \frac{4}{39}\ \frac{3}{20}\ \frac{2}{9}$	$\frac{2}{79}\ \frac{3}{89}\ \frac{1}{21}\ \frac{4}{55}$

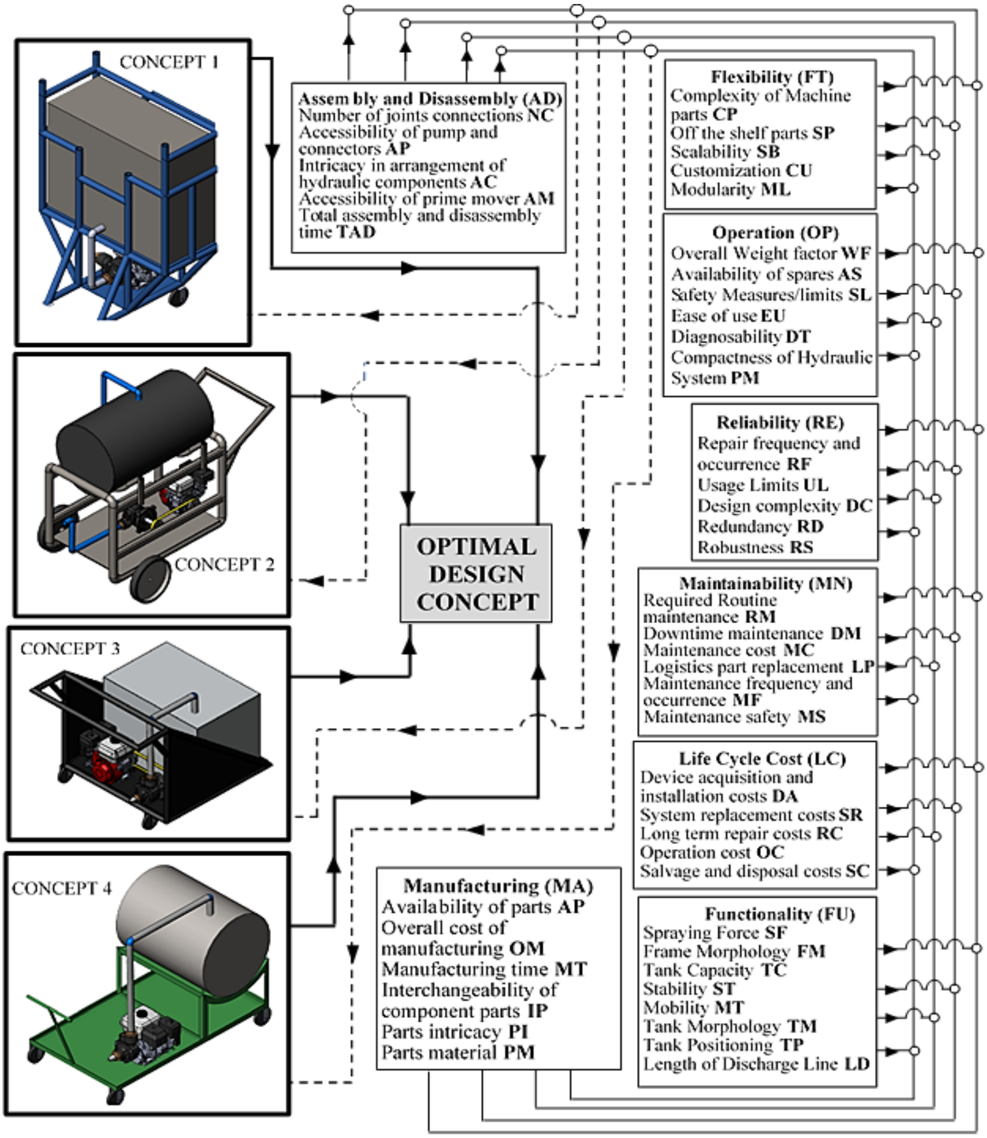

Figure 2. Application of the Integrated Model to Conceptual design of Liquid Spraying Machine

Table 3. FSEs obtained from Pairwise comparison matrices of sub features

Design Feature	**Sub features**

MA	***AP***	***OM***	***MT***	***IP***	***PI***	***PM***
	$\frac{5}{63}\ \frac{5}{41}\ \frac{17}{95}\ \frac{6}{23}$	$\frac{7}{39}\ \frac{21}{82}\ \frac{5}{14}\ \frac{1}{2}$	$\frac{3}{52}\ \frac{7}{79}\ \frac{5}{38}\ \frac{12}{61}$	$\frac{3}{64}\ \frac{4}{59}\ \frac{4}{41}\ \frac{9}{62}$	$\frac{4}{97}\ \frac{1}{18}\ \frac{5}{63}\ \frac{9}{71}$	$\frac{2}{11}\ \frac{1}{4}\ \frac{31}{90}\ \frac{11}{23}$
AD	***NC***	***AP***	***AC***	***AM***	***TAD***	
	$\frac{3}{71}\ \frac{1}{19}\ \frac{2}{29}\ \frac{7}{79}$	$\frac{2}{21}\ \frac{7}{55}\ \frac{3}{17}\ \frac{11}{46}$	$\frac{1}{9}\ \frac{14}{89}\ \frac{7}{31}\ \frac{14}{45}$	$\frac{5}{36}\ \frac{1}{5}\ \frac{2}{7}\ \frac{13}{34}$	$\frac{4}{17}\ \frac{27}{91}\ \frac{4}{9}\ \frac{7}{12}$	
FU	***FM***	***ST***	***MT***	***TM***	***LD***	
	$\frac{5}{49}\ \frac{5}{36}\ \frac{5}{26}\ \frac{16}{61}$	$\frac{3}{82}\ \frac{4}{85}\ \frac{5}{78}\ \frac{6}{67}$	$\frac{1}{8}\ \frac{9}{58}\ \frac{8}{33}\ \frac{1}{3}$	$\frac{4}{51}\ \frac{1}{9}\ \frac{10}{63}\ \frac{2}{9}$	$\frac{16}{85}\ \frac{16}{61}\ \frac{26}{71}\ \frac{31}{63}$	$\frac{4}{51}\ \frac{7}{59}\ \frac{3}{17}\ \frac{1}{4}$
LC	***DA***	***SR***	***RC***	***OC***	***SC***	
	$\frac{9}{58}\ \frac{20}{97}\ \frac{26}{95}\ \frac{10}{27}$	$\frac{2}{35}\ \frac{7}{87}\ \frac{1}{9}\ \frac{2}{13}$	$\frac{5}{47}\ \frac{10}{67}\ \frac{13}{63}\ \frac{15}{52}$	$\frac{11}{48}\ \frac{14}{45}\ \frac{5}{12}\ \frac{5}{9}$	$\frac{3}{34}\ \frac{11}{95}\ \frac{12}{79}\ \frac{16}{79}$	
MN	***RM***	***DM***	***MC***	***LP***	***MF***	***MS***
	$\frac{5}{73}\ \frac{1}{10}\ \frac{14}{97}\ \frac{4}{19}$	$\frac{3}{50}\ \frac{1}{12}\ \frac{11}{94}\ \frac{7}{41}$	$\frac{11}{70}\ \frac{11}{50}\ \frac{23}{76}\ \frac{23}{55}$	$\frac{4}{49}\ \frac{7}{60}\ \frac{15}{91}\ \frac{5}{21}$	$\frac{1}{8}\ \frac{4}{23}\ \frac{11}{46}\ \frac{1}{3}$	$\frac{5}{48}\ \frac{13}{86}\ \frac{20}{93}\ \frac{13}{42}$
RE	***RF***	***UL***	***DC***	***RD***	***RS***	
	$\frac{7}{46}\ \frac{1}{5}\ \frac{5}{19}\ \frac{22}{63}$	$\frac{2}{11}\ \frac{9}{37}\ \frac{31}{96}\ \frac{3}{7}$	$\frac{5}{67}\ \frac{10}{99}\ \frac{13}{95}\ \frac{17}{89}$	$\frac{2}{49}\ \frac{1}{20}\ \frac{1}{16}\ \frac{1}{12}$	$\frac{11}{56}\ \frac{3}{11}\ \frac{7}{19}\ \frac{1}{2}$	
OP	***WF***	***AS***	***SL***	***EU***	***DT***	***PM***
	$\frac{9}{98}\ \frac{9}{70}\ \frac{13}{73}\ \frac{1}{4}$	$\frac{1}{10}\ \frac{6}{41}\ \frac{6}{29}\ \frac{12}{41}$	$\frac{7}{74}\ \frac{1}{7}\ \frac{19}{92}\ \frac{19}{62}$	$\frac{9}{47}\ \frac{17}{63}\ \frac{22}{59}\ \frac{15}{29}$	$\frac{3}{49}\ \frac{3}{35}\ \frac{5}{41}\ \frac{2}{11}$	$\frac{3}{62}\ \frac{4}{57}\ \frac{8}{79}\ \frac{12}{79}$
FT	***CP***	***SP***	***SB***	***CU***	***ML***	
	$\frac{2}{15}\ \frac{5}{27}\ \frac{25}{97}\ \frac{17}{46}$	$\frac{3}{17}\ \frac{14}{57}\ \frac{1}{3}\ \frac{6}{13}$	$\frac{1}{9}\ \frac{11}{70}\ \frac{7}{32}\ \frac{11}{36}$	$\frac{2}{45}\ \frac{1}{18}\ \frac{1}{14}\ \frac{3}{31}$	$\frac{1}{7}\ \frac{17}{82}\ \frac{23}{79}\ \frac{20}{49}$	

The aggregates of the design alternatives from the Pugh matrices in Tables *I* to *P* in APPENDIX II are used to develop the decision matrix from which the fuzzy best and worst values can be obtained. The decision matrix, fuzzy best and worst values are presented in Table 4. Further, the separation measures are obtained from equations 15 and 16 from the fuzzified decision matrix in Table 4, weight of the design features and the fuzzified worst and best values. Also, the performance index value in the form of TrFN is obtainable from equation 17 using the separation measures. Finally, the best nonfuzzy performance value of the *nth* design alternative is obtained from the defuzzification of the fuzzified performance index by applying equation 18 and the ranking was achieved using equation 19 as presented in Table 5.

Table 4. Fuzzified Decision Matrix and Fuzzy Best and Worst Values

Design features	**Fuzzified Decision Matrix**			
	Design Concepts			
	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**

Manufacturing $\left[\frac{2}{19}\ \frac{6}{41}\ \frac{18}{89}\ \frac{2}{7}\right]$	$\frac{47}{52}\ \frac{155}{94}\ \frac{239}{77}\ \frac{31}{5}$	$\frac{115}{63}\ \frac{53}{16}\ \frac{88}{15}\ \frac{245}{23}$	$\frac{165}{98}\ \frac{305}{99}\ \frac{148}{27}\ \frac{419}{42}$	$\frac{39}{23}\ \frac{256}{83}\ \frac{307}{56}\ \frac{911}{91}$
Assembly and Disassembly $\left[\frac{5}{46}\ \frac{3}{19}\ \frac{2}{9}\ \frac{6}{19}\right]$	$\frac{5}{13}\ \frac{25}{28}\ \frac{178}{85}\ \frac{213}{47}$	$\frac{1}{2}\ \frac{73}{65}\ \frac{226}{87}\ \frac{541}{98}$	$\frac{22}{63}\ \frac{22}{27}\ \frac{110}{57}\ \frac{340}{81}$	$\frac{49}{88}\ \frac{44}{35}\ \frac{262}{89}\ \frac{44}{7}$
Functionality $\left[\frac{3}{29}\ \frac{14}{95}\ \frac{13}{63}\ \frac{16}{55}\right]$	$\frac{7}{19}\ \frac{7}{8}\ \frac{29}{14}\ \frac{313}{68}$	$\frac{7}{23}\ \frac{67}{90}\ \frac{9}{5}\ \frac{336}{83}$	$\frac{31}{68}\ \frac{94}{93}\ \frac{164}{71}\ \frac{213}{43}$	$\frac{19}{36}\ \frac{43}{37}\ \frac{183}{70}\ \frac{251}{45}$
Life cycle cost $\left[\frac{3}{55}\ \frac{3}{37}\ \frac{2}{17}\ \frac{9}{52}\right]$	$\frac{23}{90}\ \frac{3}{5}\ \frac{4}{3}\ 3$	$\frac{3}{16}\ \frac{37}{79}\ \frac{12}{11}\ \frac{200}{79}$	$\frac{1}{5}\ \frac{29}{61}\ \frac{33}{29}\ \frac{254}{97}$	$\frac{21}{76}\ \frac{41}{64}\ \frac{56}{39}\ \frac{106}{33}$
Maintainability $\left[\frac{2}{33}\ \frac{3}{34}\ \frac{11}{87}\ \frac{9}{49}\right]$	$\frac{10}{51}\ \frac{14}{29}\ \frac{83}{74}\ \frac{21}{8}$	$\frac{11}{45}\ \frac{5}{9}\ \frac{57}{47}\ \frac{100}{37}$	$\frac{14}{59}\ \frac{11}{20}\ \frac{11}{9}\ \frac{265}{96}$	$\frac{13}{69}\ \frac{16}{35}\ \frac{21}{20}\ \frac{73}{30}$
Reliability $\left[\frac{5}{91}\ \frac{4}{49}\ \frac{7}{59}\ \frac{15}{86}\right]$	$\frac{10}{39}\ \frac{52}{85}\ \frac{40}{29}\ \frac{205}{66}$	$\frac{11}{37}\ \frac{32}{47}\ \frac{55}{37}\ \frac{238}{73}$	$\frac{1}{4}\ \frac{17}{29}\ \frac{30}{23}\ \frac{148}{51}$	$\frac{11}{63}\ \frac{22}{49}\ \frac{49}{46}\ \frac{157}{63}$
Flexibility $\left[\frac{2}{79}\ \frac{3}{89}\ \frac{1}{21}\ \frac{4}{55}\right]$	$\frac{5}{68}\ \frac{15}{94}\ \frac{5}{14}\ \frac{7}{8}$	$\frac{4}{43}\ \frac{7}{36}\ \frac{11}{26}\ \frac{72}{71}$	$\frac{4}{49}\ \frac{6}{35}\ \frac{3}{8}\ \frac{17}{19}$	$\frac{7}{89}\ \frac{1}{6}\ \frac{31}{84}\ \frac{8}{9}$
Operation $\left[\frac{5}{73}\ \frac{4}{39}\ \frac{3}{20}\ \frac{2}{9}\right]$	$\frac{13}{49}\ \frac{53}{79}\ \frac{35}{22}\ \frac{87}{23}$	$\frac{1}{3}\ \frac{76}{93}\ \frac{97}{51}\ \frac{209}{47}$	$\frac{2}{7}\ \frac{49}{69}\ \frac{153}{92}\ \frac{356}{91}$	$\frac{23}{84}\ \frac{25}{37}\ \frac{74}{47}\ \frac{37}{10}$

Fuzzy Best (F^*) and Worst (F^-) values

F^*	**MA**	**AD**	**FU**	**LC**
	$\frac{115}{63}\ \frac{53}{16}\ \frac{88}{15}\ \frac{245}{23}$	$\frac{49}{88}\ \frac{44}{35}\ \frac{262}{89}\ \frac{44}{7}$	$\frac{19}{36}\ \frac{43}{37}\ \frac{183}{70}\ \frac{251}{45}$	$\frac{21}{76}\ \frac{41}{64}\ \frac{56}{39}\ \frac{106}{33}$
	MN	**RE**	**OP**	**FT**
	$\frac{11}{45}\ \frac{5}{9}\ \frac{11}{9}\ \frac{265}{96}$	$\frac{11}{37}\ \frac{32}{47}\ \frac{55}{37}\ \frac{238}{73}$	$\frac{1}{3}\ \frac{76}{93}\ \frac{97}{51}\ \frac{209}{47}$	$\frac{4}{43}\ \frac{7}{36}\ \frac{11}{26}\ \frac{72}{71}$
F^-	**MA**	**AD**	**FU**	**LC**
	$\frac{47}{52}\ \frac{155}{94}\ \frac{239}{77}\ \frac{31}{5}$	$\frac{22}{63}\ \frac{22}{27}\ \frac{110}{57}\ \frac{340}{81}$	$\frac{7}{23}\ \frac{67}{90}\ \frac{9}{5}\ \frac{336}{83}$	$\frac{3}{16}\ \frac{37}{79}\ \frac{12}{11}\ \frac{200}{79}$
	MN	**RE**	**OP**	**FT**
	$\frac{13}{69}\ \frac{16}{35}\ \frac{21}{20}\ \frac{73}{30}$	$\frac{11}{63}\ \frac{22}{49}\ \frac{49}{46}\ \frac{157}{63}$	$\frac{23}{84}\ \frac{53}{79}\ \frac{74}{47}\ \frac{37}{10}$	$\frac{5}{68}\ \frac{15}{94}\ \frac{5}{14}\ \frac{17}{19}$

Table 5. Separation Measures, Performance Index and Ranking of design concepts

Design Concepts	Separation Measures S_i	Separation Measures R_i	Performance Index VIKOR Q_i	Defuzzified Value of Q_i	Ranking
Concept 1	$\frac{21}{46}\ \frac{38}{61}\ \frac{59}{69}\ \frac{19}{16}$	$\frac{2}{19}\ \frac{6}{41}\ \frac{18}{89}\ \frac{2}{7}$	$\frac{31}{34}\ \frac{13}{16}\ \frac{19}{25}\ \frac{41}{56}$	$\frac{4}{5}$	4th
Concept 2	$\frac{17}{91}\ \frac{21}{76}\ \frac{11}{27}\ \frac{41}{67}$	$\frac{3}{29}\ \frac{14}{95}\ \frac{13}{63}\ \frac{16}{55}$	$\frac{27}{49}\ \frac{15}{29}\ \frac{21}{41}\ \frac{49}{96}$	$\frac{13}{25}$	1st
Concept 3	$\frac{17}{56}\ \frac{4}{9}\ \frac{62}{99}\ \frac{49}{52}$	$\frac{5}{46}\ \frac{3}{19}\ \frac{2}{9}\ \frac{6}{19}$	$\frac{16}{21}\ \frac{63}{83}\ \frac{3}{4}\ \frac{27}{35}$	$\frac{22}{29}$	3rd
Concept 4	$\frac{3}{8}\ \frac{49}{90}\ \frac{59}{75}\ \frac{43}{37}$	$\frac{3}{29}\ \frac{14}{95}\ \frac{13}{63}\ \frac{16}{55}$	$\frac{11}{14}\ \frac{58}{77}\ \frac{73}{98}\ \frac{29}{39}$	$\frac{43}{57}$	2nd

4. Discussions and Conclusion

Considering the results obtained from the hybridized model by integration of fuzzy AHP, Fuzzy Pugh Matrix and Fuzzy VIKOR, it is clear that design concept two is the optimal design. However, there are discrepancies in the best nonfuzzy performance value of the design alternatives. This discrepancy can be observed from the non-consistency in the difference of the final defuzzified value of the performance indices of the design alternatives. The differences in the final value of the design alternatives is an indication that the hybridized model allots values to the design alternatives according to their performance in terms of design features and sub features. Also, the higher difference between the best nonfuzzy performance of design concept two (which is the optimal design concept) and concept four (which is the second optimal design concept) is an indication that design concept two performs excellently than its close alternative in the decision process. However, the difference between concept four and concept three (which is the third optimal design concept) is very small which indicates that the performance of the two concepts is almost the same in terms of their closeness to the optimal design concept and as such the manufacturer can decide whether to select any of these two as the next option to the optimal design. However, since there is a difference between the performance of these two alternatives to design concept one (which has the least performance in the decision process), the design engineer may reconsider selecting the concept with the largest difference to concept one as the second optimal design. In essence, the final results obtained from the decision process has provided a useful insight to the design engineer and manufacturer in terms of the design concept with the best performance. In view of this, it can be hypothetically stated that the hybridized model makes distinctive decision that a design concept is better than other alternatives.

Further, it can also be stated that the improved performance of the hybridized model may be due to two reasons. The first reason is the involvement of the weights of the design features in the computation of separation measures. This increases the dependency of the best nonfuzzy performance value of the optimal design concept on weights of the design features which also causes the difference in the final values of the design concepts. In essence, a notable variation in the final values of the design concepts can be obtained from the hybridized model. The second reason is the iterative comparison which is structured by using all the design alternatives as basis and inclusion of the weight of sub features in the process of developing the elements of the fuzzified decision matrix. In the hybridized model proposed in this article, the iterative comparison of the design alternatives considering the sub features (as described Tables *I* to *P* in Appendix II) is a unique way of arriving at a decision matrix which makes it a different approach compare to other decision analysis. This ensures that all the design alternatives have been considered as basis in the decision process for each of the sub features under a design feature. This method may be considered as an elaboration of the conventional Pugh matrix in which the weights of the design features are used in conjunction with applying one of the design alternatives as the basis in the decision process. The advantage of considering all the design alternatives as basis of comparison using the weights of the sub features is that it ensures a thorough analysis in the decision process because it ensures that there is no bias judgement that can occur from apportioning of values to the availability of design features or sub features in the alternative designs. In view of this, the study has been able to proof that integrating Fuzzy AHP, Fuzzy Pugh Matrix and Fuzzy VIKOR can produce effective results for decisions on optimal design concept.

Further, a good but cumbersome way to compare the proposed hybridized model in the present study with other models is to carry out decision analysis with other models considering the same alternative designs used in the present study. This may increase the number of working tables to be presented and it may shift the purpose of the article because there will be many methods to consider. However, an excellent way to compare the proposed hybridized model with previous model is to consider the analysis involved in the development of the decision matrix. As stated earlier, it is evident that the hybridized model presented in this article allows comparison of all design alternatives by considering all the sub features in the process of developing the decision matrix because it is from the aggregates of this comparison that the elements of the design matrix are obtained. In other studies, the decision matrix is usually obtained by apportioning crisp values [5, 14] or fuzzy numbers [1] to represent the availability of design features in the design alternatives. Also, in other studies involving application of hybridized multi attribute decision models to conceptual design, the decision matrices are created by aggregating the availability of sub features in the alternative designs using fuzzy numbers [34, 35]. The reliability of these methods depends on the expertise of the design engineers to accurately quantify the availability of the sub features in the alternatives. Also, other studies that involves the application of hybridized multi attribute decision models usually employs the opinion of experts or group of decision makers to aggregate the availability of sub criteria in the alternatives in order to create the fuzzified decision matrix [28-30]. Hence the iterative approach proposed in the present study provides a non-bias fuzzified values for the elements of the decision matrix.

To this end, it can be concluded that conceptual design phase in engineering involves a decision-making process that provides optimal design concept from a set of alternative design concepts. In order to achieve the efficient selection of optimal design concept, it is necessary to consider a holistic approach by considering all necessary design features and sub features. However, the process becomes complex because of the numerous features considered. The present study has been able to prove that the application of hybridized multi-criteria decision models is a promising way of providing a systematic computation in the decision process in order to avoid the bias nature of over grading a design feature or its sub feature. The essence of these pairwise matrices is to ensure that the weights of the design features and sub features are obtained from allocation of linguistic terms in the form of trapezoidal fuzzy numbers by design experts and the fuzzy synthetic extent evaluation provides a methodical technique of deriving the weights from the pairwise matrix. Further, it is difficult to ascertain that a design concept is better than the other by apportioning of points in a decision matrix but the introduction of the fuzzified Pugh matrix using all the design concept as basis has assisted in creating an non-bias judgement process because the strength and weaknesses of all the design alternatives has been considered for all the design features. In essence, modelling decision making problem in engineering design as a multicriteria decision analysis and solving the problem using an integrated multicriteria decision analysis model is a promising approach to decision making in conceptual engineering design. However, considering the hybridized model presented in the present study, future work is possible in the aspect of developing the model into an application rather than the excel spread sheet used in the present study. Such application should be developed to enable users or decision makers to input the necessary design features and sub features alongside their relationships in order to facilitate the computational process in the decision analysis. The application may also implement a CAD based graphic interface where parts can be matched with features in order to support analysis of the alternative conceptual designs in the decision process.

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APPENDIX I

Table A. Pairwise Comparison Matrix for Sub features of Manufacturing

Manufacturing MA						
	AP	***OM***	***MT***	***IP***	***PI***	***PM***
AP	1 1 1 1	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$
OM	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	1 1 1 1	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$
MT	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	1 1 1 1	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$
IP	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	1 1 1 1	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$
PI	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	1 1 1 1	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$
PM	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	1 1 1 1
FSE	$\frac{5}{63}\ \frac{5}{41}\ \frac{17}{95}\ \frac{6}{23}$	$\frac{7}{39}\ \frac{21}{82}\ \frac{5}{14}\ \frac{1}{2}$	$\frac{3}{52}\ \frac{7}{79}\ \frac{5}{38}\ \frac{12}{61}$	$\frac{3}{64}\ \frac{4}{59}\ \frac{4}{41}\ \frac{9}{62}$	$\frac{4}{97}\ \frac{1}{18}\ \frac{5}{63}\ \frac{9}{71}$	$\frac{2}{11}\ \frac{1}{4}\ \frac{31}{90}\ \frac{11}{23}$

Table B. Pairwise Comparison Matrix for Sub features of Assembly and Disassembly

Assembly and Disassembly AD					
	NC	***AP***	***AC***	***AM***	***TAD***
NC	1 1 1 1	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$
AP	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	1 1 1 1	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$
AC	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	1 1 1 1	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$
AM	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	1 1 1 1	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$
TAD	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	1 1 1 1
FSE	$\frac{3}{71}\ \frac{1}{19}\ \frac{2}{29}\ \frac{7}{79}$	$\frac{2}{21}\ \frac{7}{55}\ \frac{3}{17}\ \frac{11}{46}$	$\frac{1}{9}\ \frac{14}{89}\ \frac{7}{31}\ \frac{14}{45}$	$\frac{5}{36}\ \frac{1}{5}\ \frac{2}{7}\ \frac{13}{34}$	$\frac{4}{17}\ \frac{27}{91}\ \frac{4}{9}\ \frac{7}{12}$

Table C. Pairwise Comparison Matrix for Sub features of Functionality

	Functionality FU					
	SF	***FM***	***ST***	***MT***	***TM***	***LD***
SF	1 1 1 1	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$
FM	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	1 1 1 1	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$
ST	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	1 1 1 1	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$
MT	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	1 1 1 1	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$
TM	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	1 1 1 1	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$
LD	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	1 1 1 1
FSE	$\frac{5}{49}\ \frac{5}{36}\ \frac{5}{26}\ \frac{16}{61}$	$\frac{3}{82}\ \frac{4}{85}\ \frac{5}{78}\ \frac{6}{67}$	$\frac{1}{8}\ \frac{9}{58}\ \frac{8}{33}\ \frac{1}{3}$	$\frac{4}{51}\ \frac{1}{9}\ \frac{10}{63}\ \frac{2}{9}$	$\frac{16}{85}\ \frac{16}{61}\ \frac{26}{71}\ \frac{31}{63}$	$\frac{4}{51}\ \frac{7}{59}\ \frac{3}{17}\ \frac{1}{4}$

Table D. Pairwise Comparison Matrix for Sub features of Life Cycle Cost

	Life Cycle Cost LC				
	DA	***SR***	***RC***	***OC***	***SC***
DA	1 1 1 1	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$
SR	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	1 1 1 1	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$
RC	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	1 1 1 1	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$
OC	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	1 1 1 1	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$
SC	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	1 1 1 1
FSE	$\frac{9}{58}\ \frac{20}{97}\ \frac{26}{95}\ \frac{10}{27}$	$\frac{2}{35}\ \frac{7}{87}\ \frac{1}{9}\ \frac{2}{13}$	$\frac{5}{47}\ \frac{10}{67}\ \frac{13}{63}\ \frac{15}{52}$	$\frac{11}{48}\ \frac{14}{45}\ \frac{5}{12}\ \frac{5}{9}$	$\frac{3}{34}\ \frac{11}{95}\ \frac{12}{79}\ \frac{16}{79}$

Table E. Pairwise Comparison Matrix for Sub features of Maintainability

Maintainability MN						
	RM	***DM***	***MC***	***LP***	***MF***	***MS***
RM	$1\ 1\ 1\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$
DM	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$1\ 1\ 1\ 1$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$
MC	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$1\ 1\ 1\ 1$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$
LP	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$1\ 1\ 1\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$
MF	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$1\ 1\ 1\ 1$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$
MS	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$1\ 1\ 1\ 1$
FSE						
	$\frac{5}{73}\ \frac{1}{10}\ \frac{14}{97}\ \frac{4}{19}$	$\frac{3}{50}\ \frac{1}{12}\ \frac{11}{94}\ \frac{7}{41}$	$\frac{11}{70}\ \frac{11}{50}\ \frac{23}{76}\ \frac{23}{55}$	$\frac{4}{49}\ \frac{7}{60}\ \frac{15}{91}\ \frac{5}{21}$	$\frac{1}{8}\ \frac{4}{23}\ \frac{11}{46}\ \frac{1}{3}$	$\frac{5}{48}\ \frac{13}{86}\ \frac{20}{93}\ \frac{13}{42}$

Table F. Pairwise Comparison Matrix for Sub features of Reliability

Reliability RE					
	RF	***UL***	***DC***	***RD***	***RS***
RF	$1\ 1\ 1\ 1$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$
UL	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$1\ 1\ 1\ 1$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$
DC	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$1\ 1\ 1\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$
RD	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$1\ 1\ 1\ 1$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$
RS	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$1\ 1\ 1\ 1$
FSE	$\frac{7}{46}\ \frac{1}{5}\ \frac{5}{19}\ \frac{22}{63}$	$\frac{2}{11}\ \frac{9}{37}\ \frac{31}{96}\ \frac{3}{7}$	$\frac{5}{67}\ \frac{10}{99}\ \frac{13}{95}\ \frac{17}{89}$	$\frac{2}{49}\ \frac{1}{20}\ \frac{1}{16}\ \frac{1}{12}$	$\frac{11}{56}\ \frac{3}{11}\ \frac{7}{19}\ \frac{1}{2}$

Table G. Pairwise Comparison Matrix for Sub features of Flexibility

Flexibility FT					
	CP	***SP***	***SB***	***CU***	***ML***
CP	$1\ 1\ 1\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$
SP	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$1\ 1\ 1\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$
SB	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$1\ 1\ 1\ 1$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$
CU	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$1\ 1\ 1\ 1$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$
ML	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$1\ 1\ 1\ 1$
FSE	$\frac{2}{15}\ \frac{5}{27}\ \frac{25}{97}\ \frac{17}{46}$	$\frac{3}{17}\ \frac{14}{57}\ \frac{1}{3}\ \frac{6}{13}$	$\frac{1}{9}\ \frac{11}{70}\ \frac{7}{32}\ \frac{11}{36}$	$\frac{2}{45}\ \frac{1}{18}\ \frac{1}{14}\ \frac{3}{31}$	$\frac{1}{7}\ \frac{17}{82}\ \frac{23}{79}\ \frac{20}{49}$

Table H. Pairwise Comparison Matrix for Sub features of Operation

Operation OP						
	WF	***AS***	***SL***	***EU***	***DT***	***PM***
WF	$1\ 1\ 1\ 1$	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$
AS	$\frac{1}{4}\ \frac{2}{7}\ \frac{1}{3}\ \frac{2}{5}$	$1\ 1\ 1\ 1$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$
SL	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$1\ 1\ 1\ 1$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$
EU	$\frac{5}{2}\ 3\ \frac{7}{2}\ 4$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$1\ 1\ 1\ 1$	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{13}{4}\ \frac{15}{4}\ \frac{17}{4}\ \frac{19}{4}$
DT	$\frac{7}{4}\ \frac{9}{4}\ \frac{11}{4}\ \frac{13}{4}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$1\ 1\ 1\ 1$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$
PM	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{2}{5}\ \frac{1}{2}\ \frac{2}{3}\ 1$	$\frac{4}{13}\ \frac{4}{11}\ \frac{4}{9}\ \frac{4}{7}$	$\frac{4}{19}\ \frac{4}{17}\ \frac{4}{15}\ \frac{4}{13}$	$1\ \frac{3}{2}\ 2\ \frac{5}{2}$	$1\ 1\ 1\ 1$
FSE	$\frac{9}{98}\ \frac{9}{70}\ \frac{13}{73}\ \frac{1}{4}$	$\frac{1}{10}\ \frac{6}{41}\ \frac{6}{29}\ \frac{12}{41}$	$\frac{7}{74}\ \frac{1}{7}\ \frac{19}{92}\ \frac{19}{62}$	$\frac{9}{47}\ \frac{17}{63}\ \frac{22}{59}\ \frac{15}{29}$	$\frac{3}{49}\ \frac{3}{35}\ \frac{5}{41}\ \frac{2}{11}$	$\frac{3}{62}\ \frac{4}{57}\ \frac{8}{79}\ \frac{12}{79}$

APPENDIX II

Table I. Fuzzified Pugh Matrix for Manufacturing using all design concept as baseline

Sub features of MA	**Design Concepts**			
	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**
AP	1 1 1 1	13/4 15/4 17/4 19/4	5/2 3 7/2 4	1 1 1 1
OM	1 1 1 1	7/4 9/4 11/4 13/4	1 3/2 2 5/2	5/2 3 7/2 4
MT	1 1 1 1	7/4 9/4 11/4 13/4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4
IP	1 1 1 1	13/4 15/4 17/4 19/4	5/2 3 7/2 4	5/2 3 7/2 4
PI	1 1 1 1	5/2 3 7/2 4	13/4 15/4 17/4 19/4	7/4 9/4 11/4 13/4
PM	1 1 1 1	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	5/2 3 7/2 4
AP	1 3/2 2 5/2	1 1 1 1	7/4 9/4 11/4 13/4	1 3/2 2 5/2
OM	5/2 3 7/2 4	1 1 1 1	1 3/2 2 5/2	13/4 15/4 17/4 19/4
MT	5/2 3 7/2 4	1 1 1 1	5/2 3 7/2 4	5/2 3 7/2 4
IP	1 3/2 2 5/2	1 1 1 1	7/4 9/4 11/4 13/4	7/4 9/4 11/4 13/4
PI	7/4 9/4 11/4 13/4	1 1 1 1	5/2 3 7/2 4	1 3/2 2 5/2
PM	1 3/2 2 5/2	1 1 1 1	1 1 1 1	7/4 9/4 11/4 13/4
AP	7/4 9/4 11/4 13/4	5/2 3 7/2 4	1 1 1 1	7/4 9/4 11/4 13/4
OM	13/4 15/4 17/4 19/4	7/4 9/4 11/4 13/4	1 1 1 1	13/4 15/4 17/4 19/4
MT	1 3/2 2 5/2	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1
IP	7/4 9/4 11/4 13/4	5/2 3 7/2 4	1 1 1 1	1 1 1 1
PI	1 3/2 2 5/2	5/2 3 7/2 4	1 1 1 1	7/4 9/4 11/4 13/4
PM	1 3/2 2 5/2	1 1 1 1	1 1 1 1	5/2 3 7/2 4
AP	1 1 1 1	13/4 15/4 17/4 19/4	5/2 3 7/2 4	1 1 1 1
OM	7/4 9/4 11/4 13/4	7/4 9/4 11/4 13/4	7/4 9/4 11/4 13/4	1 1 1 1
MT	1 3/2 2 5/2	1 3/2 2 5/2	1 1 1 1	1 1 1 1
IP	7/4 9/4 11/4 13/4	5/2 3 7/2 4	1 1 1 1	1 1 1 1
PI	5/2 3 7/2 4	5/2 3 7/2 4	13/4 15/4 17/4 19/4	1 1 1 1
PM	7/4 9/4 11/4 13/4	5/2 3 7/2 4	5/2 3 7/2 4	1 1 1 1
Agg	$\frac{47}{52}$ $\frac{155}{94}$ $\frac{239}{77}$ $\frac{31}{5}$	$\frac{115}{63}$ $\frac{53}{16}$ $\frac{88}{15}$ $\frac{245}{23}$	$\frac{165}{98}$ $\frac{305}{99}$ $\frac{148}{27}$ $\frac{419}{42}$	$\frac{39}{23}$ $\frac{256}{83}$ $\frac{307}{56}$ $\frac{911}{91}$

Table J. Fuzzified Pugh matrix for Assembly and Disassembly using all design concept as baseline

Sub features of AD	**Design Concepts**			
	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**
NC	1 1 1 1	5/2 3 7/2 4	5/2 3 7/2 4	13/4 15/4 17/4 19/4
AP	1 1 1 1	5/2 3 7/2 4	7/4 9/4 11/4 13/4	5/2 3 7/2 4
AC	1 1 1 1	13/4 15/4 17/4 19/4	7/4 9/4 11/4 13/4	1 3/2 2 5/2
AM	1 1 1 1	1 1 1 1	1 1 1 1	5/2 3 7/2 4
TAD	1 1 1 1	5/2 3 7/2 4	1 1 1 1	13/4 15/4 17/4 19/4
NC	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	5/2 3 7/2 4
AP	7/4 9/4 11/4 13/4	1 1 1 1	1 3/2 2 5/2	1 1 1 1
AC	1 3/2 2 5/2	1 1 1 1	1 3/2 2 5/2	1 3/2 2 5/2
AM	1 1 1 1	1 1 1 1	1 1 1 1	5/2 3 7/2 4
TAD	7/4 9/4 11/4 13/4	1 1 1 1	7/4 9/4 11/4 13/4	5/2 3 7/2 4
NC	1 3/2 2 5/2	7/4 9/4 11/4 13/4	1 1 1 1	5/2 3 7/2 4
AP	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	7/4 9/4 11/4 13/4
AC	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1	7/4 9/4 11/4 13/4
AM	7/4 9/4 11/4 13/4	7/4 9/4 11/4 13/4	1 1 1 1	7/4 9/4 11/4 13/4
TAD	1 3/2 2 5/2	7/4 9/4 11/4 13/4	1 1 1 1	1 3/2 2 5/2
NC	7/4 9/4 11/4 13/4	1 1 1 1	5/2 3 7/2 4	1 1 1 1
AP	5/2 3 7/2 4	5/2 3 7/2 4	5/2 3 7/2 4	1 1 1 1
AC	5/2 3 7/2 4	13/4 15/4 17/4 19/4	7/4 9/4 11/4 13/4	1 1 1 1
AM	1 1 1 1	1 1 1 1	5/2 3 7/2 4	1 1 1 1
TAD	1 1 1 1	5/2 3 7/2 4	13/4 15/4 17/4 19/4	1 1 1 1
Agg	$\frac{5}{13}$ $\frac{25}{28}$ $\frac{178}{85}$ $\frac{213}{47}$	$\frac{1}{2}$ $\frac{73}{65}$ $\frac{226}{87}$ $\frac{541}{98}$	$\frac{22}{63}$ $\frac{22}{27}$ $\frac{110}{57}$ $\frac{340}{81}$	$\frac{49}{88}$ $\frac{44}{35}$ $\frac{262}{89}$ $\frac{44}{7}$

Table K. Fuzzified Pugh Matrix for Functionality using all design concept as baseline

Sub features of FU	Design Concepts			
	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**
SF	1 1 1 1	1 3/2 2 5/2	7/4 9/4 11/4 13/4	13/4 15/4 17/4 19/4
FM	1 1 1 1	1 3/2 2 5/2	7/4 9/4 11/4 13/4	5/2 3 7/2 4
ST	1 1 1 1	7/4 9/4 11/4 13/4	13/4 15/4 17/4 19/4	5/2 3 7/2 4
MT	1 1 1 1	5/2 3 7/2 4	5/2 3 7/2 4	13/4 15/4 17/4 19/4
TM	1 1 1 1	7/4 9/4 11/4 13/4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4
LD	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
SF	1 3/2 2 5/2	1 1 1 1	1 3/2 2 5/2	1 3/2 2 5/2
FM	7/4 9/4 11/4 13/4	1 1 1 1	1 3/2 2 5/2	1 3/2 2 5/2
ST	1 3/2 2 5/2	1 1 1 1	5/2 3 7/2 4	1 3/2 2 5/2
MT	1 3/2 2 5/2	1 1 1 1	7/4 9/4 11/4 13/4	7/4 9/4 11/4 13/4
TM	1 3/2 2 5/2	1 1 1 1	1 1 1 1	1 3/2 2 5/2
LD	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
SF	5/2 3 7/2 4	7/4 9/4 11/4 13/4	1 1 1 1	13/4 15/4 17/4 19/4
FM	5/2 3 7/2 4	7/4 9/4 11/4 13/4	1 1 1 1	5/2 3 7/2 4
ST	1 3/2 2 5/2	1 3/2 2 5/2	1 1 1 1	7/4 9/4 11/4 13/4
MT	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	5/2 3 7/2 4
TM	1 3/2 2 5/2	1 3/2 2 5/2	1 1 1 1	1 1 1 1
LD	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
SF	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	7/4 9/4 11/4 13/4	1 1 1 1
FM	13/4 15/4 17/4 19/4	5/2 3 7/2 4	7/4 9/4 11/4 13/4	1 1 1 1
ST	5/2 3 7/2 4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1
MT	7/4 9/4 11/4 13/4	5/2 3 7/2 4	1 1 1 1	1 1 1 1
TM	5/2 3 7/2 4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1
LD	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
Agg	$\frac{7}{19}\ \frac{7}{8}\ \frac{29}{14}\ \frac{313}{68}$	$\frac{7}{23}\ \frac{67}{90}\ \frac{9}{5}\ \frac{336}{83}$	$\frac{31}{68}\ \frac{94}{93}\ \frac{164}{71}\ \frac{213}{43}$	$\frac{19}{36}\ \frac{43}{37}\ \frac{183}{70}\ \frac{251}{45}$

Table L. Fuzzified Pugh Matrix for Life Cycle Cost using all design concept as baseline

Sub features of LC	Design Concepts			
	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**
DA	1 1 1 1	5/2 3 7/2 4	1 3/2 2 5/2	7/4 9/4 11/4 13/4
SR	1 1 1 1	7/4 9/4 11/4 13/4	5/2 3 7/2 4	5/2 3 7/2 4
RC	1 1 1 1	1 3/2 2 5/2	5/2 3 7/2 4	13/4 15/4 17/4 19/4
OC	1 1 1 1	1 3/2 2 5/2	7/4 9/4 11/4 13/4	5/2 3 7/2 4
SC	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DA	5/2 3 7/2 4	1 1 1 1	1 3/2 2 5/2	1 3/2 2 5/2
SR	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	1 3/2 2 5/2
RC	1 3/2 2 5/2	1 1 1 1	7/4 9/4 11/4 13/4	1 3/2 2 5/2
OC	7/4 9/4 11/4 13/4	1 1 1 1	1 3/2 2 5/2	1 3/2 2 5/2
SC	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DA	13/4 15/4 17/4 19/4	5/2 3 7/2 4	1 1 1 1	5/2 3 7/2 4
SR	7/4 9/4 11/4 13/4	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1
RC	1 1 1 1	1 3/2 2 5/2	1 1 1 1	5/2 3 7/2 4
OC	5/2 3 7/2 4	5/2 3 7/2 4	1 1 1 1	5/2 3 7/2 4
SC	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DA	7/4 9/4 11/4 13/4	7/4 9/4 11/4 13/4	1 3/2 2 5/2	1 1 1 1
SR	5/2 3 7/2 4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1
RC	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	5/2 3 7/2 4	1 1 1 1
OC	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	5/2 3 7/2 4	1 1 1 1
SC	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
Agg	$\frac{23}{90}\ \frac{3}{5}\ \frac{4}{3}\ 3$	$\frac{3}{16}\ \frac{37}{79}\ \frac{12}{11}\ \frac{200}{79}$	$\frac{1}{5}\ \frac{29}{61}\ \frac{33}{29}\ \frac{254}{97}$	$\frac{21}{76}\ \frac{41}{64}\ \frac{56}{39}\ \frac{106}{33}$

Table M. Fuzzified Pugh Matrix for Maintainability using all design concept as baseline

Sub features of MN	Design Concepts			
	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**
RM	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DM	1 1 1 1	5/2 3 7/2 4	5/2 3 7/2 4	7/4 9/4 11/4 13/4
MC	1 1 1 1	13/4 15/4 17/4 19/4	5/2 3 7/2 4	13/4 15/4 17/4 19/4
LP	1 1 1 1	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 3/2 2 5/2
MF	1 1 1 1	5/2 3 7/2 4	5/2 3 7/2 4	7/4 9/4 11/4 13/4
MS	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
RM	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DM	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	1 3/2 2 5/2
MC	1 3/2 2 5/2	1 1 1 1	7/4 9/4 11/4 13/4	1 1 1 1
LP	1 3/2 2 5/2	1 1 1 1	1 1 1 1	1 3/2 2 5/2
MF	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	1 3/2 2 5/2
MS	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
RM	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DM	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	1 3/2 2 5/2
MC	7/4 9/4 11/4 13/4	5/2 3 7/2 4	1 1 1 1	5/2 3 7/2 4
LP	1 3/2 2 5/2	1 1 1 1	1 1 1 1	1 3/2 2 5/2
MF	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	1 3/2 2 5/2
MS	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
RM	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DM	5/2 3 7/2 4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1
MC	1 3/2 2 5/2	1 1 1 1	7/4 9/4 11/4 13/4	1 1 1 1
LP	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1
MF	5/2 3 7/2 4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1
MS	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
Agg	$\frac{10}{51}$ $\frac{14}{29}$ $\frac{83}{74}$ $\frac{21}{8}$	$\frac{11}{45}$ $\frac{5}{9}$ $\frac{57}{47}$ $\frac{100}{37}$	$\frac{14}{59}$ $\frac{11}{20}$ $\frac{11}{9}$ $\frac{265}{96}$	$\frac{13}{69}$ $\frac{16}{35}$ $\frac{21}{20}$ $\frac{73}{30}$

Table N. Fuzzified Pugh Matrix for Reliability using all design concept as baseline

Sub features of RE	**Design Concepts**			
	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**
RF	1 1 1 1	5/2 3 7/2 4	7/4 9/4 11/4 13/4	1 3/2 2 5/2
UL	1 1 1 1	5/2 3 7/2 4	5/2 3 7/2 4	1 3/2 2 5/2
DC	1 1 1 1	7/4 9/4 11/4 13/4	7/4 9/4 11/4 13/4	5/2 3 7/2 4
RD	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
RS	1 1 1 1	13/4 15/4 17/4 19/4	5/2 3 7/2 4	7/4 9/4 11/4 13/4
RF	7/4 9/4 11/4 13/4	1 1 1 1	1 3/2 2 5/2	1 3/2 2 5/2
UL	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	1 3/2 2 5/2
DC	5/2 3 7/2 4	1 1 1 1	1 1 1 1	5/2 3 7/2 4
RD	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
RS	1 3/2 2 5/2	1 1 1 1	7/4 9/4 11/4 13/4	1 3/2 2 5/2
RF	5/2 3 7/2 4	13/4 15/4 17/4 19/4	1 1 1 1	7/4 9/4 11/4 13/4
UL	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	1 3/2 2 5/2
DC	5/2 3 7/2 4	1 1 1 1	1 1 1 1	5/2 3 7/2 4
RD	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
RS	7/4 9/4 11/4 13/4	5/2 3 7/2 4	1 1 1 1	1 3/2 2 5/2
RF	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	5/2 3 7/2 4	1 1 1 1
UL	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1
DC	7/4 9/4 11/4 13/4	1 3/2 2 5/2	1 3/2 2 5/2	1 1 1 1
RD	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
RS	5/2 3 7/2 4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1
Agg	$\frac{10}{39}\ \frac{52}{85}\ \frac{40}{29}\ \frac{205}{66}$	$\frac{11}{37}\ \frac{32}{47}\ \frac{55}{37}\ \frac{238}{73}$	$\frac{1}{4}\ \frac{17}{29}\ \frac{30}{23}\ \frac{148}{51}$	$\frac{11}{63}\ \frac{22}{49}\ \frac{49}{46}\ \frac{157}{63}$

Table O. Fuzzified Pugh Matrix for Flexibility using all design concept as baseline

Sub features of FT	Design Concepts			
	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**
CP	1 1 1 1	1 3/2 2 5/2	7/4 9/4 11/4 13/4	5/2 3 7/2 4
SP	1 1 1 1	13/4 15/4 17/4 19/4	5/2 3 7/2 4	5/2 3 7/2 4
SB	1 1 1 1	5/2 3 7/2 4	7/4 9/4 11/4 13/4	1 1 1 1
CU	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
ML	1 1 1 1	5/2 3 7/2 4	13/4 15/4 17/4 19/4	7/4 9/4 11/4 13/4
CP	13/4 15/4 17/4 19/4	1 1 1 1	5/2 3 7/2 4	13/4 15/4 17/4 19/4
SP	1 3/2 2 5/2	1 1 1 1	7/4 9/4 11/4 13/4	7/4 9/4 11/4 13/4
SB	7/4 9/4 11/4 13/4	1 1 1 1	1 3/2 2 5/2	7/4 9/4 11/4 13/4
CU	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
ML	7/4 9/4 11/4 13/4	1 1 1 1	5/2 3 7/2 4	1 3/2 2 5/2
CP	5/2 3 7/2 4	7/4 9/4 11/4 13/4	1 1 1 1	5/2 3 7/2 4
SP	7/4 9/4 11/4 13/4	5/2 3 7/2 4	1 1 1 1	1 1 1 1
SB	5/2 3 7/2 4	13/4 15/4 17/4 19/4	1 1 1 1	5/2 3 7/2 4
CU	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
ML	1 3/2 2 5/2	7/4 9/4 11/4 13/4	1 1 1 1	7/4 9/4 11/4 13/4
CP	7/4 9/4 11/4 13/4	1 3/2 2 5/2	1 3/2 2 5/2	1 1 1 1
SP	7/4 9/4 11/4 13/4	13/4 15/4 17/4 19/4	1 1 1 1	1 1 1 1
SB	1 1 1 1	5/2 3 7/2 4	7/4 9/4 11/4 13/4	1 1 1 1
CU	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
ML	5/2 3 7/2 4	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1
Agg	$\frac{5}{68}\ \frac{15}{94}\ \frac{5}{14}\ \frac{7}{8}$	$\frac{4}{43}\ \frac{7}{36}\ \frac{11}{26}\ \frac{72}{71}$	$\frac{4}{49}\ \frac{6}{35}\ \frac{3}{8}\ \frac{17}{19}$	$\frac{7}{89}\ \frac{1}{6}\ \frac{31}{84}\ \frac{8}{9}$

Table P. Fuzzified Pugh Matrix for Operation using all design concept as baseline

Sub features of OP	**Design Concepts**			
	Concept 1	**Concept 2**	**Concept 3**	**Concept 4**
WF	1 1 1 1	5/2 3 7/2 4	5/2 3 7/2 4	13/4 15/4 17/4 19/4
AS	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
SL	1 1 1 1	5/2 3 7/2 4	5/2 3 7/2 4	1 1 1 1
EU	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DT	1 1 1 1	13/4 15/4 17/4 19/4	5/2 3 7/2 4	5/2 3 7/2 4
PM	1 1 1 1	13/4 15/4 17/4 19/4	7/4 9/4 11/4 13/4	1 3/2 2 5/2
WF	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	5/2 3 7/2 4
AS	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
SL	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	7/4 9/4 11/4 13/4
EU	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DT	1 3/2 2 5/2	1 1 1 1	7/4 9/4 11/4 13/4	1 3/2 2 5/2
PM	1 3/2 2 5/2	1 1 1 1	1 3/2 2 5/2	1 3/2 2 5/2
WF	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	5/2 3 7/2 4
AS	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
SL	7/4 9/4 11/4 13/4	1 1 1 1	1 1 1 1	7/4 9/4 11/4 13/4
EU	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DT	7/4 9/4 11/4 13/4	5/2 3 7/2 4	1 1 1 1	1 1 1 1
PM	5/2 3 7/2 4	13/4 15/4 17/4 19/4	1 1 1 1	7/4 9/4 11/4 13/4
WF	1 3/2 2 5/2	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	1 1 1 1
AS	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
SL	1 1 1 1	5/2 3 7/2 4	5/2 3 7/2 4	1 1 1 1
EU	1 1 1 1	1 1 1 1	1 1 1 1	1 1 1 1
DT	7/4 9/4 11/4 13/4	13/4 15/4 17/4 19/4	1 1 1 1	1 1 1 1
PM	13/4 15/4 17/4 19/4	13/4 15/4 17/4 19/4	5/2 3 7/2 4	1 1 1 1
Agg	$\frac{13}{49}\ \frac{53}{79}\ \frac{35}{22}\ \frac{87}{23}$	$\frac{1}{3}\ \frac{76}{93}\ \frac{97}{51}\ \frac{209}{47}$	$\frac{2}{7}\ \frac{49}{69}\ \frac{153}{92}\ \frac{356}{91}$	$\frac{23}{84}\ \frac{25}{37}\ \frac{74}{47}\ \frac{37}{10}$