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A Fuzzy Based Approach for New Product Concept Evaluation and Selection

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Abstract

Product developers make many decisions during the early stages of product development which have a profound impact on the final cost of the product. These decisions include selecting a product concept that best meet customer needs. Product concept selection involves using the collective knowledge of many experts who possess different backgrounds and expertise in various fields to evaluate a set of product concepts developed to meet certain customer needs. This paper proposes a concept evaluation and selection methodology capable of capturing the fuzziness and vagueness impeded in concept evaluation. The proposed methodology integrates the Weighted Concept Selection Matrix with the Analytical Hierarchal Process (AHP) under a Fuzzy environment. The developed methodology has the capability of capturing the fuzziness and vagueness in the concept evaluators' ratings. The methodology consists of eight steps that begins with retrieving the product concepts, developing the evaluation criteria and selecting the evaluators, and ends up by choosing the best concept. The criteria are prioritized and assigned fuzzy weights according to their importance with respect to the nature of the product and based on the capabilities of the manufacturing company. Furthermore, the evaluators are prioritized and assigned fuzzy weights with respect to the criteria based on their different backgrounds. These weights are aggregated with the concepts' fuzzy rating done by the evaluators in order to compute a final score for each concept. The usage of the methodology is verified and tested by using an illustrative example.

Keywords: Product Design, Fuzzy systems, Multi-criteria Decision Making, Analytical Hierarchal Process

1. Introduction

New Product Development process (NPD) is the set of activities required to bring a new concept to a state of market readiness, beginning with the perception of a market opportunity and ending with the production, sale, and delivery of a product (Ulrich and Eppinger, 2011). Decisions made during the early stages of product development have a profound impact on the final product. Product development practitioners state that about 70% of the final cost of the developed product is committed during the early stages of product development (Boothroyd et al. 1994). These stages mainly include customers' needs analysis, setting target specifications, concept generation, concept selection, concept testing, and setting final specifications. These stages are considered to be the fuzzy-front end of the product development process and the success of new products rely to a great extent on the performance of the product development team in dealing with these stages.

Product development teams undergo two modes of thinking while dealing with the fuzzy-front end of the product development process. The first mode is a divergent mode where a large variety of ideas and concepts are sought. The second mode of thinking is a convergent mode where product solutions are finalized by setting final specifications capable of meeting customers' needs. The transition between the modes is done through concept selection where a large number of concepts must be evaluated based on an agreed upon set of criteria.

Concept selection involves using the collective knowledge of many experts who possess different backgrounds and expertise in various fields to evaluate a set of product concepts developed to meet certain customer needs. Experts evaluate concepts based on a set of criteria that takes into account the nature of the product and the functions it is supposed to meet; furthermore, criteria that correspond to some special enterprise needs such as the availability of the production facilities needed to produce the concepts understudy could also be added (Ullah et. Al, 2012). The criteria correspond to various organizational needs and thus could have different levels of importance. Thus it is crucial to prioritize the criteria based on the needs of the organization where the development is taking place (Gangurde and Akarte, 2011). In the same manner, it is essential to prioritize the opinions of the experts with respect to the different criteria. Criteria and experts' prioritization, in addition to concepts evaluation processes are associated with a great degree of vagueness which could be captured through the use of fuzzy linguistics.

This paper presents a concept evaluation and selection methodology that can capture the fuzziness associated with people judgments during the concept evaluation and selection phase. This is accomplished through integrating the use of Fuzzy-AHP and the weighted concept selection matrix. The rest of the paper is organized as follows. A review of the concept evaluation techniques is presented section in section 2. Next, the methodology is presented section 3. After that, a case where the methodology was implemented to select a new product concept is illustrated in section 4.

2. Review of Concept Evaluation and Selection Techniques

Concept evaluation techniques used by product development practitioners can be classified into two broad categories based on the precision of evaluation used into:

2.1 Precise techniques

Precise concept evaluation and selection techniques are those techniques that assume the availability of information about new product concepts and the ability of the product development team to quantify the performance of the new product concepts against the evaluation criteria such as the concept selection matrix developed by Pugh (1991). This technique is based on a matrix as shown in Figure 1, where the new concepts are compared with respect to each other or to a specific concept (datum). The concepts are compared and the advantages (+) and disadvantages (-) of each one with respect to the datum are counted, where equal importance to the datum are given (s). Concepts with many (-) are discarded, while concepts with some (+) and some (-) may undergo some modification in order to be improved or could be combined with other concepts leading to generating new concepts. Evaluation continues in the same manner until the best alternative is selected.

	Concepts				
	1	2	3	5	6
Criterion 1	DATUM	S	-	+	+
Criterion 2		-	-	-	+
Criterion 3		S	-	S	+
Criterion 4		S	S	+	+
∑ +		0	0	2	4
∑ -		1	4	1	0
∑ S		3	1	1	0

Figure 1. Pugh Concept Selection Matrix

Ulrich and Eppinger (2011) extended Pugh's matrix taking into consideration the fact that new product development has to pass through different stages before deciding which alternative to choose. The process proposed includes two major steps, concept screening and concepts selection. Concept screening involves reducing the number of alternatives to a certain level; while in concept selection the results of the screening phase are scored and tested in order to select the best one among them. Figure 2 shows the weighted matrix used for concept selection. The concepts are rated with respect to the criteria using a crisp evaluation scale, usually from 1 to 9. Next, a weighted score for each concept with respect to each criterion is calculated based on the pre-determined criteria weights. The weighted score for a certain concept at a certain criterion is calculated by multiplying the associated rating by that criterion weight. After that, the weighted scores for each concept are summed and the one that gets the highest score is selected as the best concept.

Criteria	Criteria Weights	Concepts					
		Concept 1		Concept 2		Concept 3	
		Rate	Weighted Score	Rate	Weighted Score	Rate	Weighted Score
Criterion 1	w_1						
Criterion 2	w_2						
Criterion 3	w_3						
TOTAL	100%		Score 1		Score 2		Score 3

Figure 2. Weighted Concept Selection Matrix

2.2 Imprecise techniques

Product development practitioners realized that concept evaluation is mainly concerned with the selection of the best alternative based on information that can be characterized as being:

- Unquantifiable information such as comfort or degree of satisfaction. These are qualitative data that cannot be physically measured.
- Incomplete information where the data is not exact.
- Non-obtainable information, such as when the cost of obtaining the data is too high or when the data is not available.
- Partial ignorance, when the situation is not fully understood

The nature of information needed to perform product concept selection renders it as an imprecise problem that can be dealt with using fuzzy decision making tools and techniques. For example; Wang (2001) developed an outranking preference model based on the possibility theory. Lin and Chen (2004) introduced the Go/No-Go evaluation for the design at the front end as another approach, where fuzzy linguistic approach was applied once for all the alternatives leading to the selection of the most suitable alternative according to predetermined criteria. Ayag (2005) developed a two-stage methodology to incorporate fuzzy logic into a pairwise comparison of Analytic Hierarchy Process (AHP) and simulation for final concept selection. Chan and Kumar (2006) introduced Fuzzy-Extended-AHP (FEAHP) approach using triangular fuzzy numbers to represent decision makers' comparison judgments and fuzzy synthetic extent analysis method to decide the final priority of different decision criteria. Ayag and Özdemir (2009) developed an approach using fuzzy Analytic Network Process (ANP) to evaluate a set of conceptual design alternatives. Geng et. al. (2010) proposed an integrated design concept evaluation approach based on vague sets.

It was noted from the literature that most practitioners deal with the process of assigning weights to criteria without considering the backgrounds of the evaluators. This results in assigning equal weights to all evaluators, which may seem like a logical thing to do since the evaluators are part of the same team and were presented similar information. But; this ignores the fact that the evaluators may have different technical backgrounds which means that their opinion should not be treated in a similar manner with respect to all criteria. This paper presents a methodology that can be used to evaluate and select the best product concepts while taking into account the different technical backgrounds of the evaluators. The methodology is based on integrating Fuzzy Logic and Analytic Hierarchy Process (AHP) into the Weighted Concept Selection Matrix as will be illustrated in the subsequent section.

3. Fuzzy-AHP Concept Selection Methodology

The aim of this research is to develop a concept evaluation and selection methodology that captures the vagueness and fuzziness associated with people judgments during this stage. The proposed methodology fuzzily prioritizes criteria based on the analysis of customers' needs and the capabilities of the manufacturing company. The proposed methodology (Figure 3) starts by retrieving a set of new product concepts that are to be evaluated from the product design team. Next, a set of decision criteria are developed. The concepts retrieved in the first step will be rated with respect to these criteria in the following steps. Then, the evaluators are chosen. Those evaluators are responsible for rating the concepts retrieved in earlier stages with respect to the criteria developed. After that, a pairwise comparison between the criteria using the AHP method based on fuzzy linguistic variables in order to get a fuzzy weight for each criterion is conducted. Then, a pairwise comparison between the evaluators with respect to each criterion using the AHP method based on fuzzy linguistic variables is made. This comparison will result in a fuzzy weight for each evaluator with respect to each criterion. After that, experts (evaluators) individually rate the different concepts with respect to the selected criteria using fuzzy linguistic variables. Finally, the results of the ratings obtained from each evaluator are aggregated resulting in a global Matrix containing the fuzzy sum of weighted ratings based on the fuzzy weights of the evaluators. The fuzzy weighted ratings in the global Weighted Concept Selection Matrix in addition to the fuzzy weights of the criteria will be utilized to get a final fuzzy score for each concept.

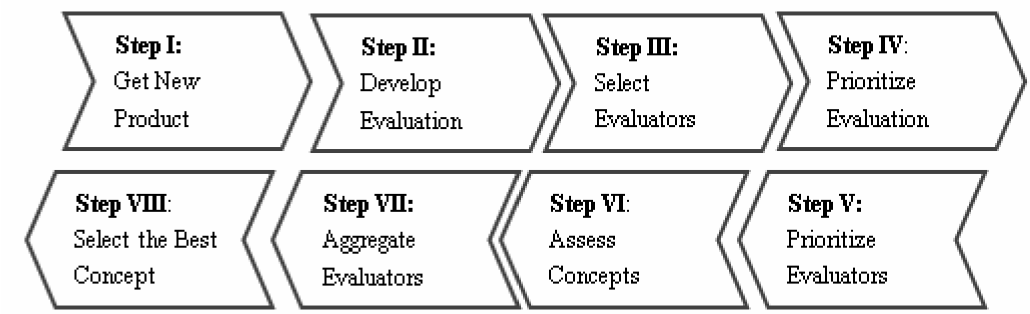

Figure 3. New Product Concept Mythology

3.1 Step I: Get New Product Concepts

Concept selection is needed to select from a set of new product concepts that are thought to meet a pre-identified market need. These concepts are usually developed during the early stages of the new product development (NPD) process. The NPD process starts by conducting a market analysis that will result in identifying a set of customers' needs. These needs are studied, analyzed, and then the product design team will generate a set of product concepts that can satisfy the customers' needs under consideration. The concepts generated will undergo two stages; concept screening during which the generated concepts are nominated and a set of usually four or five concepts are chosen to enter the second stage which is concept selection. The methodology introduced in this paper deals with the second stage where four or five concepts need to be evaluated and the best concept will be selected for further development.

3.2 Step II: Develop Evaluation Criteria

The product development team needs to develop a set of criteria to differentiate between the new product concepts. The evaluation criteria should take into account both the new product's characteristics and the firm's technological competency. It is well noted here that the evaluation criteria will differ based on the nature of the product and firm.

3.3 Step III: Select Evaluators

Evaluators are those experts whose main responsibility -in the proposed methodology- is to evaluate the new product concepts with respect to the evaluation criteria. The experts usually come from different areas of specializations in order to cover the largest possible number of products' development aspects. The evaluators could include potential users or customers.

3.4 Step IV: Prioritize Evaluation Criteria

During this step, the product development team assigns fuzzy weights to each criterion. Criteria fuzzy weights are assigned as a result of performing fuzzy pairwise comparison between the criteria using Fuzzy-AHP based model as shown Figure 4 and explained in the subsequent section.

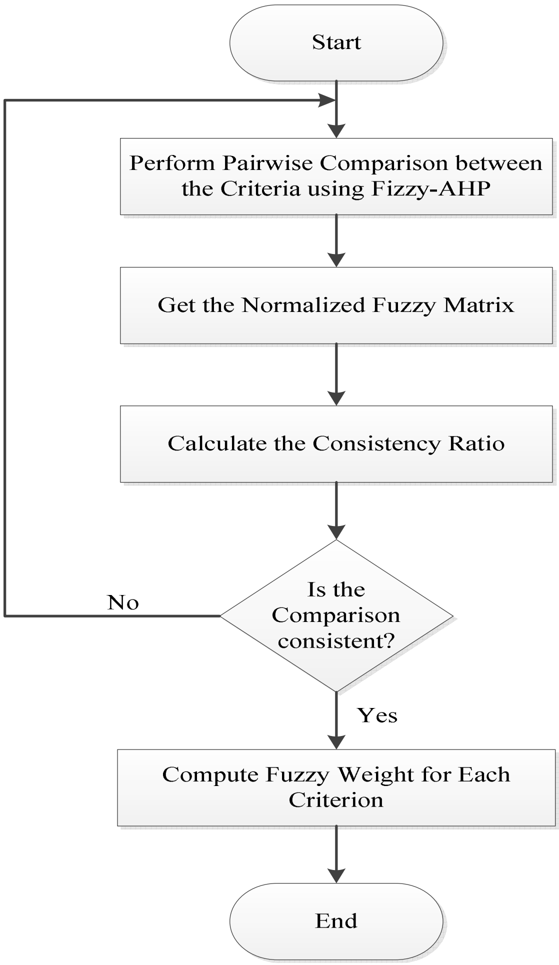

Figure 4. Procedure for Assigning Criteria Weights

I. Identifying Linguistic Variables

The linguistic variables used in the proposed methodology are expressed using positive linear trapezoidal membership functions as shown in Figure 5, where the fuzzy evaluation scale is defined in Table 1.

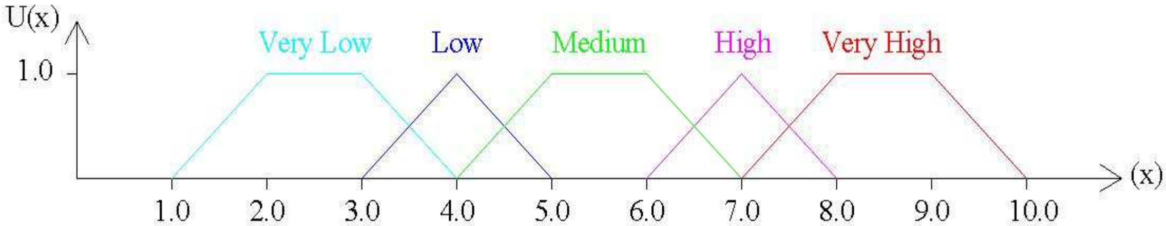

Figure 5. Linguistic Variables' Membership Functions

Table 1. Fuzzy Linguistic Comparison Scale

RATING	DESCRIPTION	Trapezoidal Membership Function
S	Same or Equally Preferred	[1, 1, 1, 1]
N	Very Lowly Preferred	[1, 2, 3, 4]
L	Lowly Preferred	[3, 4, 4, 5]
M	Moderately Preferred	[4, 5, 6, 7]
H	Highly Preferred	[6, 7, 7, 8]
Y	Very Highly Preferred	[7, 8, 9, 10]

Triangular membership's functions are special cases of the trapezoidal where the two medium values are the same. The fuzzy membership function associated with the "Equal" linguistic variable is in the form of [1, 1, 1, 1] which is the multiplicative identity of trapezoidal fuzzy numbers (Chan and Kumar, 2006) and (Yeo et al., 2004).

II. Fuzzy-AHP Comparison Model

At this stage a pairwise comparison will be performed between the evaluation criteria. The comparison is done using Fuzzy-AHP matrix. The criteria prioritization process is described in the following pseudo code.

Algorithm: Assigning Criteria Fuzzy Weights Using Fuzzy-AHP

Input: Linguistic Pairwise Comparison between Criteria C_{11} to C_{ij},

where C_{ij} is the Pairwise Comparison between Criterion i and Criterion j.

Output: Fuzzy Weight for each Criterion.

Begin:

{Criteria Weights}

Let sumcol(j) represents the summation of elements in column j in the Fuzzy-AHP matrix.

For j ← 1 To number of criteria Do

  Sum elements in column j

For i ← 1 To number of criteria Do

  For j ← 1 To number of criteria Do

    N_{ij} ← Divide C_{ij} by sumcol(j), where N_{ij} is the element in the normalized matrix relative to C_{ij}

{Check Consistency}

Let sumrow(i) represents the summation of elements in row i in the normalized matrix

For i ← 1 To number of criteria Do

  sumrow(i) ← sum elements in row i

  w_i ← sumrow(i)/number of criteria, where w_i is the fuzzy weight for criterion i

End

Applying the previous approach will result in getting a fuzzy weight for each criterion in the form of;

$$wc_i = [wc_{ia}, wc_{ib}, wc_{ic}, wc_{id}]$$

where; $\boldsymbol{wc_i}$: the fuzzy weight of criterion $\boldsymbol{i}$.

III. Checking Consistency of Pairwise Comparison

Before taking any decision based on the weights resulting from the AHP, a consistency check must be done to ensure that the values entered in the AHP matrix lacks any contradictions. The consistency check will be performed by transforming the fuzzy AHP matrix to an equivalent crisp one and computing the consistency ratio. The defuzzification method used to map a trapezoidal fuzzy number into a crisp one is based on calculating the expected value of the trapezoidal fuzzy number. The expected value for a fuzzy variable ξ is defined as shown in Equation 1 (Liu and Liu, 2002) provided that at least one of the two integrals is finite.

$$E[\xi] = \int_0^{+\infty} Cr\{\xi \geq r\}dr - \int_{-\infty}^{0} Cr\{\xi \leq r\}dr \qquad \text{Eqn. 1}$$

Where,

Cr: is the credibility measure, based on both the possibility and necessity measures.[1]

Therefore; for a trapezoidal fuzzy variable ξ = [A, B, C, D], the expected value could be represented in the form

[1] For further information about the credibility measure and the proof of Equation 1 see (Liu and Liu, 2002)

of Equation 2; (Liu and Liu, 2002) and (Xiangbai and Qunxiong, 2006)

$$E[\xi]=\frac{1}{4}[A+B+C+D] \qquad \text{Eqn. 2}$$

For a triangular fuzzy variable ξ = [A, B, C], the expected value could be represented in the form of Equation 3. .

$$E[\xi]=\frac{1}{4}[A+2B+C] \qquad \text{Eqn.3}$$

The procedure of defuzzifying the Fuzzy-AHP matrix and calculating the consistency ratio is described in the following pseudo algorithm:

Algorithm: Perform a Consistency Check for a Pairwise Comparison

Input: Linguistic Pairwise Comparison between Alternatives.

Output: Consistency Ratio

Begin:

{Consistency Check}

Let A_{ij} = [w_{ij}, x_{ij}, y_{ij}, z_{ij}] be a linguistic pairwise comparison between alternative i and alternative j.

For i ← 1 To number of alternatives Do

For j ← 1 To number of alternatives Do

Defuzzify the comparison matrix: F_{ij} ← 0.25 * [w_{ij} + x_{ij} + y_{ij} + z_{ij}]

Let sumcol(j) represents the summation of elements in column j in the Defuzzied-AHP matrix.

For j ← 1 To number of alternatives Do

Sum elements in column j

For i ← 1 To number of alternatives Do

For j ← 1 To number of alternatives Do

N_{ij} ← Divide F_{ij} by sumcol(j), where N_{ij} is the element in the normalized matrix relative to F_{ij}

Let sumrow(i) represents the summation of elements in row i in the normalized matrix

For i ← 1 To number of alternatives Do

sumrow(i) ← sum elements in row i

w_i ← sumrow(i)/number of alternatives, where w_i is the weight of alternative i

Let CM_i be the consistency measure for alternative i

For i ← 1 To number of alternatives Do

For j ← 1 To number of alternatives Do

CM_i ← sum F_{ij} * w_j

CM_i ← CM_i / w_i

Let CI be the consistency index

For i ← 1 To number of alternatives Do

CI ← sum CM_i

CI ← ((CI / number of alternatives) – number of alternatives) / (number of alternatives -1)

Let RI be the Random Index and CR the Consistency Ratio

CR ← CI / RI

CR <=? 0.01 Then comparisons are consistent

End

3.5 Step V: Prioritize Evaluators with respect to Criteria

In this step fuzzy weights for the team members (evaluators) with respect to each criterion will be assigned. Evaluators who will evaluate the concepts have different backgrounds and expertise in different areas. Assigning fuzzy weights for each evaluator with respect to each criterion will help in capturing the differences in members' specializations and in getting more consistent results. These weights are assigned as a result of performing the fuzzy pairwise comparison between the evaluators with respect to the decision criteria using the Fuzzy-AHP approach. Figure 6 shows a flowchart describing the process of assigning evaluators' fuzzy weights.

The process of assigning the experts' weights is done using the following pseudo code:

Algorithm: Assigning Experts' Fuzzy Weights with respect to each Criterion Using Fuzzy-AHP

Input: Linguistic Pairwise Comparison between Experts T_{111} to T_{ijk}, where T_{ijk} is the pairwise comparison between expert i and expert j with respect to criterion k.

Output: Fuzzy Weight for each Expert with respect to each Criterion.

Begin:

{Experts' Weight}

For k ← 1 To number of criteria Do

Let sumcol(j) represents the summation of elements in column j in the Fuzzy-AHP matrix.

For j ← 1 To number of experts Do

    Sum elements in column j

For i ← 1 To number of experts Do

    For j ← 1 To number of experts Do

    NT_{ij} ← Divide T_{ij} by sumcol(j), where NT_{ij} is the element in the normalized matrix.

{Check Consistency}

Let sumrow(i) represents the summation of elements in row i in the normalized matrix

For i ← 1 To number of experts Do

    sumrow(i) ← sum elements in row i

    wt_{ik} ← sumrow(i)/number of experts, where wt_{ik} is the fuzzy weight for expert i with respect to criterion k

End

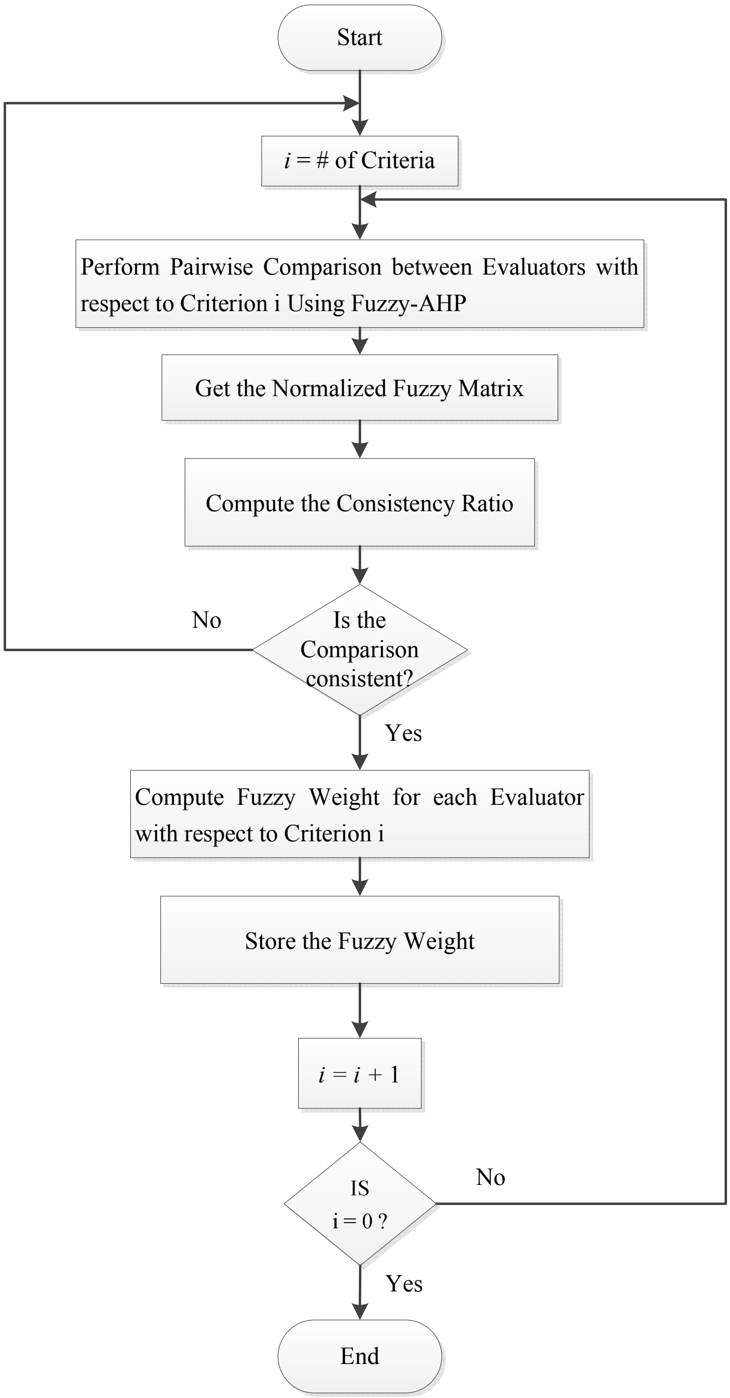

Figure 6. Procedure for Assigning Evaluators' Weights

If there exists ***j*** experts, the second stage will yield fuzzy weights for the experts in the form;

$$w_{ji} = [w_{jia}, w_{jib}, w_{jic}, w_{jid}]$$

where; $\boldsymbol{w_{ji}}$: the fuzzy weight of evaluator ***j*** with respect to criterion ***i***.

In this case also, the consistency check should be performed for each pairwise comparison matrix using the procedure described earlier.

3.6 Step VI: Assess Concepts

Each evaluator is asked to rate ***k*** concepts using the fuzzy linguistic variables using the concept evaluation matrix shown in Table 2, where; $\boldsymbol{r_{kji}}$: is the fuzzy rating for concept *k* done by evaluator *j* with respect to criterion *i*.

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Table 2. Concept Evaluation Matrix for Rating k Concepts Using Linguistic Variables

	CONCEPTS			
CRITERIA	Concept 1	Concept 2	…	Concept k
Criterion 1	r_{1j1}	r_{2j1}	…	r_{kj1}
Criterion 2	r_{1j2}	r_{2j2}	…	r_{kj2}
. . .	. . .	. . .	. . .	. . .
Criterion i	r_{1ji}	r_{2ji}	…	r_{kji}

Before starting the assessment process a full description of both the concepts to be evaluated and the evaluation criteria should be given to the evaluators. It should be ensured that all the evaluators understand exactly what is meant by each criterion and what the features of every concept are; otherwise, the assessment process will be affected by misunderstandings that will yield wrong evaluation results. The assessment process is described in the flowchart shown in Figure 7. It is essential to mention here that the evaluator rates the concepts using the Concept Evaluation Matrix without having any idea about the weights of the criteria or his/her own weight on each criterion.

3.7 Step VII: Aggregate Evaluators Ratings

This step aims at aggregating the evaluators' ratings to get one global Weighted Concept Selection Matrix that will be used to calculate the final concept score. The aggregation of the matrices is done as explained in the following pseudo code.

Algorithm: Aggregate the Concept Evaluation Matrices

Input: Linguistic Rating for each Concept with respect to each Criterion from each Evaluator

Fuzzy Weight for each Evaluator with respect to each Criterion

Output: Aggregated Weighted Concept Selection Matrix

Begin:

{Aggregation}

Let CR_{ij} be the elements in the aggregated Weighted Concept Selection matrix

For i ← 1 To number of concepts Do

For j ← 1 To number of criteria Do

For k ← 1 To number of experts Do

CR_{ij} = sum (Rating of expert k on concept i with respect to criterion j) * (fuzzy weight of expert k with respect to criterion j)

End

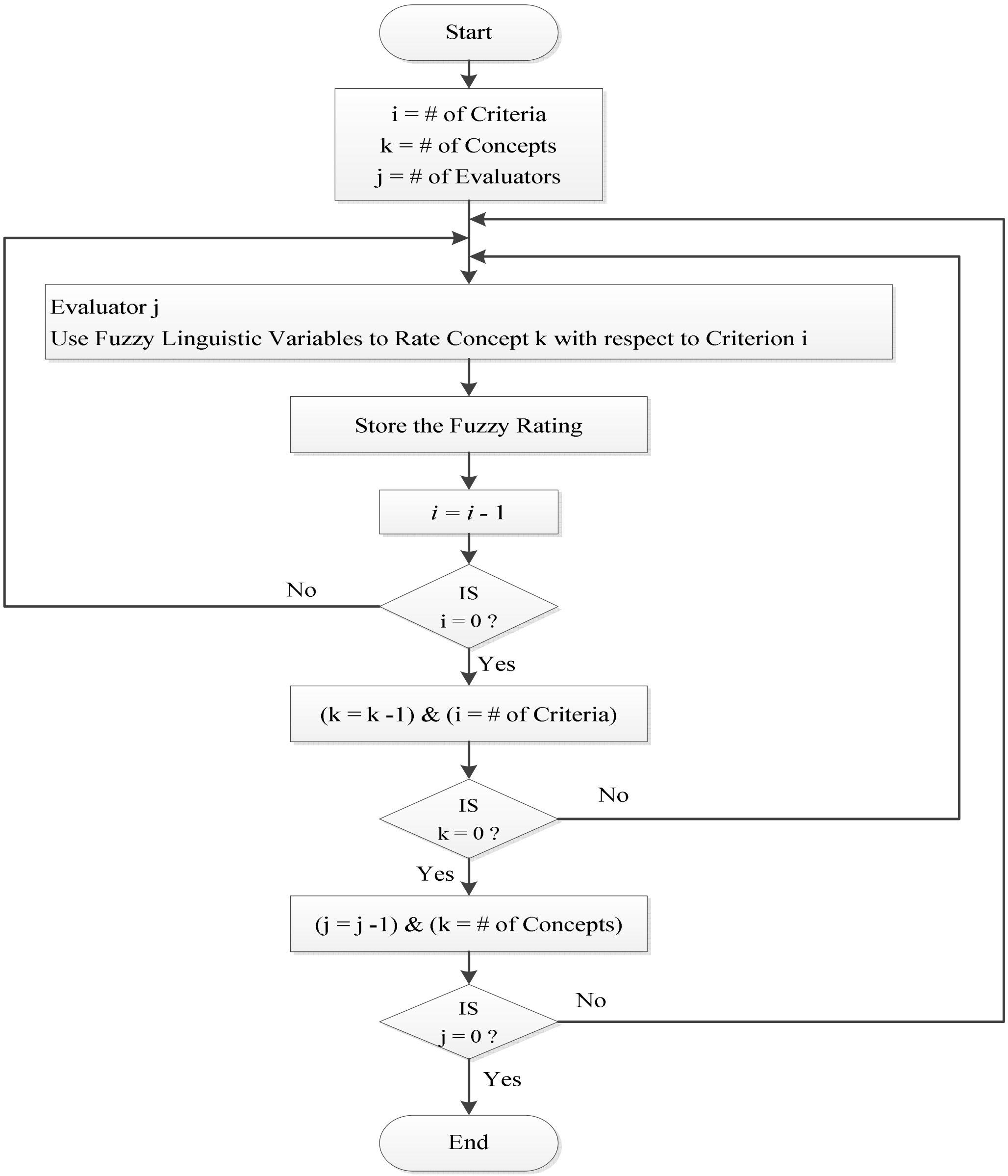

Figure 7. Procedure for the Concept Assessment Process

The aggregation process is performed in two stages; the first stage is to modify the Concept Evaluation Matrices filled by the experts into a form including the fuzzy weights of both the criteria and the evaluators as shown in Table 3, where;

$\boldsymbol{Wc_i}$: is the fuzzy weight of criterion i

$\boldsymbol{W_{ji}}$: is the fuzzy weight of evaluator j with respect to criterion i

Table 3. Modified Concept Evaluation Matrix for Rating k Concepts using Linguistic Variables.

Evaluator j			Concepts			
CRITERIA	Criterion Weight	Evaluator Weight	Concept 1	Concept 2	…	Concept k
Criterion 1	wc_1	w_{j1}	r_{1j1}	r_{2j1}	…	r_{kj1}
Criterion 2	wc_2	w_{j2}	r_{1j2}	r_{2j2}	…	r_{kj2}
. . .	. . .	. . .	. . .	. . .	. . .	. . .
Criterion i	wc_i	w_{ji}	r_{1ji}	r_{2ji}	…	r_{kji}

The second stage is to aggregate the weighted concept evaluation matrices of the ***j*** evaluators taking into consideration the evaluators fuzzy weights and ratings. The aggregation is done by summing the fuzzy weighted rating of each concept at each criterion. Table 4 illustrates the aggregated weighted concept selection matrix, where;

$\sum_{j=1}^{n} w_{ji} r_{kji}$: is the aggregated weighted rating of concept *k* on criterion *i* among all experts

Table 4. Aggregated Weighted Concept Selection Matrix

		Concepts			
Criteria	**Criterion Weight**	Concept 1	Concept 2	…	Concept k
Criterion 1	wc_1	$\sum_{j=1}^{n} w_{j1} r_{1j1}$	$\sum_{j=1}^{n} w_{j1} r_{2j1}$	…	$\sum_{j=1}^{n} w_{j1} r_{kj1}$
Criterion 2	wc_2	$\sum_{j=1}^{n} w_{j2} r_{1j2}$	$\sum_{j=1}^{n} w_{j2} r_{2j2}$	…	$\sum_{j=1}^{n} w_{j2} r_{kj2}$
. . .	. . .	. . .	. . .	. . .	. . .
Criterion i	wc_i	$\sum_{j=1}^{n} w_{ji} r_{1ji}$	$\sum_{j=1}^{n} w_{ji} r_{2ji}$	…	$\sum_{j=1}^{n} w_{ji} r_{kji}$

3.8 Step VIII: Select the Best Concept

The overall fuzzy score for each concept is calculated in this step by summing the results of multiplying the fuzzy weighted ratings resulting from the preceding step by the fuzzy weight of each criterion where the result will be the fuzzy score of concept ***j*** as represented by Equation (4)

$$S_k = \sum_{i=1}^{n} wc_i \sum_{j=1}^{m} w_{ji} r_{kji} \qquad \text{Eqn. } 4$$

where;

n: number of criteria.
m: number of concepts.
S_k: The final fuzzy score for concept *k*.
wc_i: The fuzzy weight of criterion *i*.
w_{ji}: The fuzzy weight of evaluator *j* on criterion *i*.
r_{kji}: The rating for concept *k* by evaluator *j* with respect to criterion *i*.

The following pseudo code provides an algorithm to calculate the final fuzzy score of each concept:

Algorithm: Calculate a Final Fuzzy Score for each Concept
Input: Aggregated Concept Selection Matrix Elements and Fuzzy Weight for each Criterion
Output: Fuzzy Score for each Concept
Begin:
{Final Concept Score}
Let FCS_i be the final fuzzy score of concept i
Let CR_{ij} be the elements in the aggregated Concept Selection matrix
For i ← 1 To number of concepts Do
  For j ← 1 To number of criteria Do

FCS_i = sum (CR_{ij} * fuzzy weight of criterion j)

End

The concept that received the highest score should be selected. The scores here are fuzzy and need a special technique in order to differentiate between them in order to decide which one had the highest score. This can be done by applying the Vertex Method developed by (Chen *et al*., 2006) as shown in the following pseudo code.

Algorithm: Rank the Concepts
Input: Fuzzy Score for each Concept
Output: Ranked Concepts
Begin:
{Ranking}
Let FPIS be the fuzzy positive ideal solution
Let FNIS be the fuzzy negative ideal solution
For i ← 1 To number of concepts
  Calculate the Distance from FPIS
  Calculate the Distance from FNIS
  Calculate the Closeness Coefficient
End

FPIS and FNIS are defined as shown in Equations (5) and (6).

$$FPIS = [v^+, v^+, v^+, v^+] \qquad \text{Equation 5}$$

$$FNIS = [v^-, v^-, v^-, v^-] \qquad \text{Equation 6}$$

Where:

$v^+ = \max\{a_4\}$ in the set of fuzzy numbers

$v^- = \min\{a_1\}$ in the set of fuzzy numbers

Closeness coefficient is defined as shown in Equation

$$CC_n = \frac{d_n^-}{d_n^+ + d_n^-} \qquad \text{Equation 7}$$

Where:

d_n^- : the distance between the n^th fuzzy number and the FNIS

d_n^+ : the distance between the n^th fuzzy number and the FPIS

The distance between two trapezoidal fuzzy numbers A and B is defined in Equations (8), (9), and (10):

$$A = [A_1, A_2, A_3, A_4] \qquad \text{Equation 8}$$

$$B = [B_1, B_2, B_3, B_4] \qquad \text{Equation 9}$$

$$d_{AB} = \sqrt{0.25\left((A_1 - B_1)^2 + (A_2 - B_2)^2 + (A_3 - B_3)^2 + (A_4 - B_4)^2\right)} \qquad \text{Equation 10}$$

4. Illustrative Example

In the section, the developed methodology was used to evaluate four new product concepts with respect to four criteria. The evaluation team consisted of five experts in various technical fields. The product concepts and the criteria will not be disclosed in this paper due to a confidentiality agreement with the company where the case took place. The results of the implementation were as following:

4.1 Step I: Get Product Concepts

Four product concepts developed by a product development team were evaluated {P1, P2, P3, P4}. These concepts were fully explained to the evaluators ensuring that each team member understood exactly the functionality, features, and components of each design.

4.2 Step II: Develop Product Concepts Evaluation Criteria

Four criteria were used {C1, C2, C3, C4}

4.3 Step III: Select Evaluators

Five evaluators {E1, E2, E3, E4, E5} were selected to participate in the evaluation process. The evaluators were selected to cover various expertise such as design, manufacturing, marketing, and quality.

4.4 Step IV: Prioritize Product Concepts Evaluation Criteria

The pairwise comparison between the criteria and the fuzzy weights for each criteria computed using the Fuzzy-AHP were found to be as shown in Figure 8. The Consistency Ratio (C.R.) for the comparisons was 0.095 which is acceptable.

	C1	C2	C3	C3
C1	S	1/L	1/H	1/L
C2	L	S	1/N	N
C3	H	N	S	L
C4	L	1/N	1/L	S

$$wc_1 = [0.038, 0.055, 0.062, 0.096]$$
$$wc_2 = [0.128, 0.220, 0.308, 0.550]$$
$$wc_3 = [0.291, 0.468, 0.601, 0.961]$$
$$wc_4 = [0.094, 0.143, 0.168, 0.299]$$

Figure 8. Criteria pairwise comparison and fuzzy weights

4.5 Step VI: Prioritize Evaluators with respect to Criteria

This step aims at assigning different weights to each evaluator with respect to the criteria used so as to give more weight to the opinion of experts in some field over others who do not possess the same expertise. That is, the opinion of a manufacturing expert is more important than a logistics expert when evaluating the manufacturability of a product concept. The evaluators were compared with respect to each criterion using fuzzy variables, and the resulting fuzzy weights were as shown in Table 5.

Table 5. Evaluators' fuzzy weights with respect to each criterion

	C1	**C2**	**C3**	**C4**
E1	[.027, .035, .038, .051]	[.037, .053, .067, .098]	[.039, .055, .067, .096]	[.265, .412, .535, .832]
E2	[.135, .179, .189, .256]	[.163, .204, .232, .300]	[.173, .317, .469, .746]	[.046, .068, .079, .114]
E3	[.054, .075, .077, .109]	[.035, .044, .048, .068]	[.039, .055, .067, .096]	[.022, .031, .038, .054]
E4	[.120, .165, .170, .237]	[.231, .272, .280, .339]	[.151, .212, .288, .442]	[.096, .143, .176, .294]
E5	[.378, .509, .566, .755]	[.308, .395, .407, .530]	[.151, .212, .288, .442]	[.145, .228, .316, .523]

4.6 Step VI: Assess Concepts

Each evaluator was asked to use the fuzzy linguistic variables to assess all the concepts across all criteria. The responses of evaluators 2 and 3 are shown in Table 6 and Table 7.

Table 6. Evaluator 2 assessments

P1	P2	P3	P4
H	L	M	N
L	M	H	M
N	Y	H	L
L	N	H	L

Table 7. Evaluator 3 assessments

P1	P2	P3	P4
L	Y	Y	N
Y	H	H	L
Y	L	N	L
Y	L	H	H

4.7 Steps VII and VIII: Aggregate Evaluators Ratings and Select the Best Concept

The assessments obtained by the five different evaluators were aggregated and found to be as shown in Table 8 and the total fuzzy score for each product concepts were found to be as in Table 9.

Table 8. Weighted Concept Selection Matrix.

	P 1	P 2	P 3	P 4
C 1	[0.136, 0.318, 0.394, 0.961]	[0.147, 0.339, 0.431, 1.038]	[0.153, 0.351, 0.457, 1.092]	[0.051, 0.155, 0.244, 0.650]
C 2	[0.552, 1.331, 2.082, 5.561]	[0.586, 1.469, 2.218, 5.819]	[0.560, 1.467, 2.421, 6.342]	[0.396, 1.054, 1.605, 4.417]
C 3	[0.838, 2.537, 4.922, 13.829]	[0.570, 1.797, 3.834, 9.966]	[0.547, 1.671, 3.197, 9.495]	[0.617, 1.895, 3.726, 10.84]
C 4	[0.221, 0.641, 0.993, 3.355]	[0.101, 0.356, 0.699, 2.536]	[0.313, 0.858, 1.374, 4.428]	[0.155, 0.483, 0.774, 2.709]

Table 9. Product Concepts total fuzzy scores and final rank

Product Concept	Total Fuzzy Score	Closeness Coefficient	Rank
P1	[1.747, 4.827, 8.391, 23.706]	0.421	1st
P2	[1.404, 3.961, 7.182, 19.359]	0.356	3rd
P3	[1.573, 4.347, 7.449, 21.357]	0.386	2nd
P4	[1.219, 3.587, 6.349, 18.256]	0.341	4th

5. Conclusion

A new product concept evaluation and selection based on Fuzzy-AHP has been developed. The developed methodology can capture the fuzziness and vagueness associated with people judgments during the concept selection stage. The developed methodology can fuzzily prioritize criteria based on the analysis of customers' needs and the capabilities of the manufacturing company. The methodology extends the concept evaluation matrix by integrating the AHP method with Fuzzy Logic principles in order to get a weighted fuzzy rating for each concept. A fuzzy-based AHP method is used to assign fuzzy weights for the criteria, as well as, fuzzy weights for each team member with respect to each criterion based on his/her field of specialization or the background from where he/she comes.

The developed concept evaluation and selection methodology allows the evaluators to represent their own opinion while rating the concepts individually without being affected by others. The usage of fuzzy concepts allows that capturing of vagueness inherited in the evaluators' judgments at this early stage of the product development process. It should be noted here that outcome of the methodology is dependent on the weights assigned to the evaluators and the weights given to the criteria. Thus, extra caution must be taken when assigning the weights in order to minimize the possibility of biasing the results. Although the effect of bias was reduced by using the AHP and its consistency measure. There still exists a need to develop a formal method for assigning evaluators' and criteria weights.

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