A FUZZY-BASED DECISION MAKING APPROACH FOR PRODUCT CONCEPT SELECTION

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ABSTRACT

Selecting the best product concept is one of critical tasks in product development process. Making decisions at this stage becomes very difficult due to imprecise and uncertain product requirements. This paper presents the framework of product concept selection that integrates the fuzzy set theory and the analytic hierarchy process (AHP). In the proposed approach, the fuzzy membership function is employed in performing "pairwise comparison" between competing alternatives and a "reference" on each of the criteria. The use of a reference is due to the difficulty in consistently comparing concepts to one another. The comparisons are also used to obtain the relative importance of criteria with respect to the overall objective. Once pairwise comparisons are completed, vector aggregates are computed through the use of an original AHP method and fuzzy arithmetic operations. A numerical example is presented to illustrate the approach.

Keywords : Fuzzy set theory, analytic hierarchy process (AHP), multi criteria decision making.

1. INTRODUCTION

In today's fast-paced competitive market, the ability to launch a new product better and faster becomes a fundamental prerequisite for each company to stay in competition. Developing a new product that will be successful in the market requires a series of right decisions early at the design stage. One of decisions that needs to be correctly made during the design stage is selecting the best product concept that is worth developing. Product concept selection belongs to *multi criteria decision-making* (MCDM) problems. In MCDM problems, a decision maker has to pick the best concept among a set of alternatives or product concepts based on a set of criteria or attributes. Comparing alternatives or product concepts to one another and ranking them are the pivotal roles in making the decision in such cases.

Product concept selection during product development process is an iterative process that narrows the number of concepts quickly and selects the best concept. Several concept selection methods have been proposed (Pahl, 1996; Pugh, 1990). In ranking the product concepts, it is commonly assumed that decision makers can assign the relative weight of decision criteria and evaluate each alternative with respect to each selection criterion. However, in case of conflicting alternatives, the task of picking the best concept becomes extremely difficult due to the imprecise or ambiguous data, which is norm in this type of decision problems (Aouam, 2003). Therefore, a new approach is required to perform product concept selection in product development process. The new approach should be robust enough for handling impreciseness of the product concept at the preliminary design stage.

During product development process, decision makers often deal with objects that are difficult to describe. In the absence of complete and precise information, the fuzzy set theory becomes an effective tool for modeling complex systems. On the other hand, the analytic hierarchy process (AHP) becomes extensively used in dealing with MCDM problems. An important advantage of using AHP is its ability to help decision makers detect inadvertent misjudgments in pairwise comparisons. The objective of this paper is to present a Fuzzy Modified Analytic Hierarchy Process with a Reference, a new approach that integrates the fuzzy set theory and the analytic hierarchy process using a *reference* in selecting the best product concept.

2. AN OVERVIEW OF ANALYTIC OF HIERARCHY PROCESS

Since firstly introduced in 1980 (Saaty, 1980), the analytic hierarchy process becomes extensively used in solving multi criteria decision making (MCDM) problems. In MCDM problems, a decision maker is to select the best alternative among a set of alternatives with respect to the selection criteria. AHP has been applied in a wide variety of decision areas including resource allocation, forecasting, total quality management, business process re-engineering, quality function deployment, and the balanced scorecard (Forman, 2001). There are three basic steps in using AHP: (1) Given $i=1,\ldots,m$ criteria, determine their relative weights, w_i with respect to the objective; (2) for each criteria i, compare the $j=1,\ldots,n$ alternatives and determine their relative weights w_{ij} with respect to criteria i; and (3) determine the final alternative weights W_j with respect to all the criteria by $W_j=w_{1j}w_1+w_{2j}w_2+\ldots+w_{mj}w_m$. The alternatives are then ranked by W_j. The most preferred alternative is the one having the largest W_j. Figure 1 shows a hierarchical presentation of a decision.

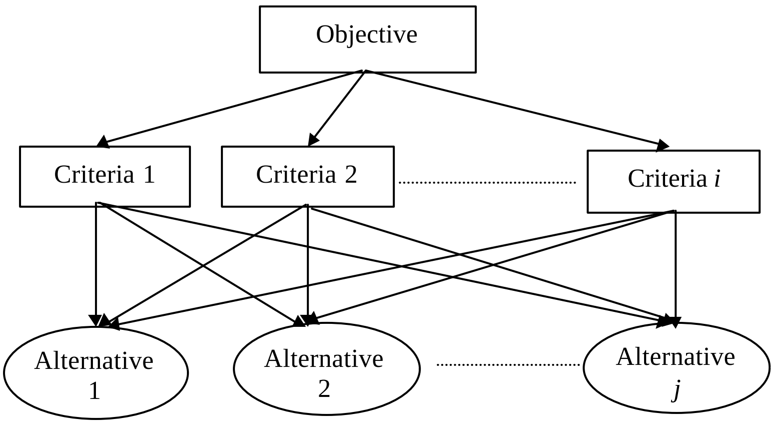


Figure 1. Hierarchical Presentation of a Decision

In Figure 1, a three-level hierarchy presentation is shown. The top or the first level is the objective of the decision problem. The second level is the set of criteria to be considered in achieving the objective. The third level or the lowest level is the set of mutually exclusive alternatives. It should be noted that a hierarchy may have more than three levels, i.e. the criteria level can be extended into several sub-criteria levels.

In performing pairwise comparisons, a decision maker is guided by a pairwise comparison scale. Table 1 presents the scale typically used in the analytic hierarchy process. For example, if a decision maker believes that alternative 1 is strongly more important than alternative 2 with respect to a certain criteria, then he or she gives a value of 5 for this judgment.

Table 1. Pairwise Comparison Scale

Numerical rating	Judgment or Preference	Remarks
1	Equally important	Two attributes contribute equally to the attribute at the higher decision level
3	Moderately more important	Experience and judgment slightly favor one attribute over another
5	Strongly more important	Experience and judgment strongly favor one attribute over another
7	Very strongly more important	Experience and judgment very strongly favor one attribute over another; its dominance has been demonstrated in practice
9	Extremely more important	Experience and judgment extremely favor one attribute over another; the evidence favoring one attribute over another is of the highest possible order of affirmation.
2,4,6,8	Intermediate values	Used when compromise is needed

After completing pairwise comparisons, a pairwise comparison matrix can be obtained as follows:

$$P = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots w_2/w_n \\ . & . & . \\ . & . & . \\ w_n/w_1 & w_n/w_2 & \dots w_n/w_n \end{bmatrix}$$

where n represents the number of items that need to be compared. If there are n items, a total of $n(n-1)/2$ judgments are needed. For example, if we are comparing 3 criteria with respect to the overall objective, even though we will have a pairwise comparison matrix of 3 by 3, but we just need to do 3 judgments, that are comparing criteria 1 and 2, criteria 1 and 3, and criteria 2 and 3. One important advantage of using AHP is that it can detect the consistency during performing pairwise comparisons. In practice, inconsistency can occur inadvertently and is still acceptable.

3. AN OVERVIEW OF PRODUCT CONCEPT DEVELOPMENT

After identifying a set of customer needs and target specifications, a product development team will generate a number of product concepts from which the team will select the best one. Product concept selection is an iterative process that includes concept screening and concept scoring. Figure 2 shows the successive and narrowing and temporary widening of a set of concept during concept development phase (Ulrich and Eppinger, 2003).

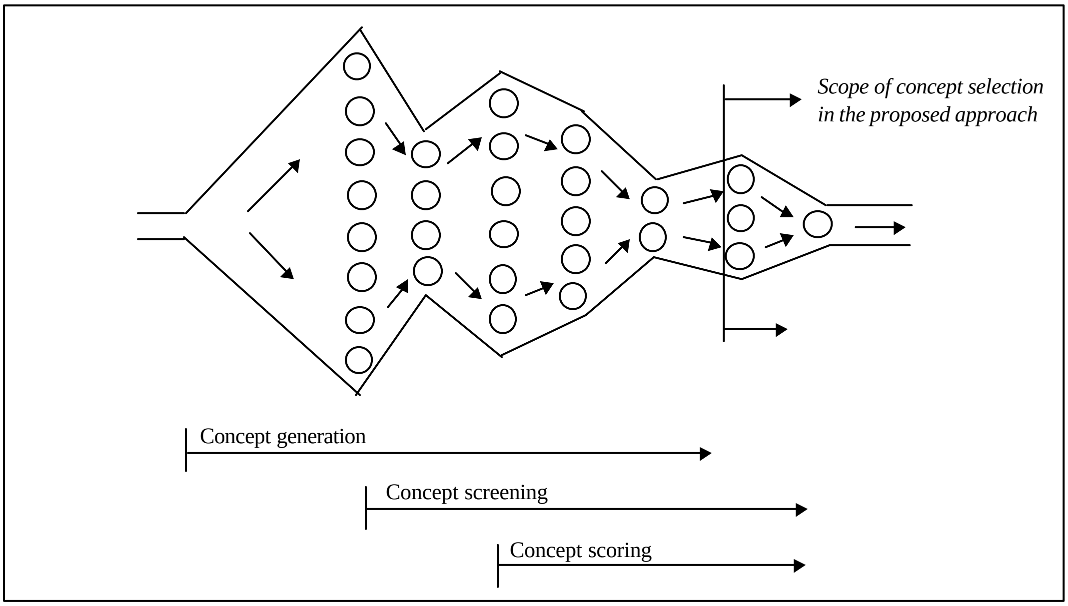


Figure 2. Concept Development Phase

The purpose of concept screening is to narrow the number of product concept quickly and to improve the concept (Pugh, 1990). There are three possible outcomes resulted from the concept screening: (1) superior concept (2) inferior concept and (3) revised and/or new concept. A superior concept is a concept that is worth considering to be further assessed, while an inferior concept needs to be thrown out since it is not worth considering. In some cases, one concept is actually worth considering with a minor revision or there can be certain concepts that can be combined into a new concept. The new concept here incorporates all good qualities coming from each concept. After having a set of concept candidates consisting of superior concepts and revised or new concepts, the concept scoring then takes place. At this stage, the product development team weighs the relative weight of the selection criteria and evaluates each product concept with respect to each selection criterion. The concept scores are determined by the weighted sum of the rating. The concept with the highest score is then selected. As seen in Figure 2, the scope of concept selection in this research only covers the last stage of concept scoring.

Given the imprecision of the concept description at the preliminary design stage, it is very difficult to consistently compare concept to one another. In the proposed approach, it is of interest to use a *reference concept* against which all other concepts are compared. The reference can be an industry standard or a commercially available product, a best-in-class benchmark product, an earlier generation of the product, any one of the concepts under consideration, or a combination of subsystem assembled to represent the best features of different products (Ullrich and Eppinger, 2003).

When available, it is always recommended to use objective metrics as the basis for evaluating a product concept with respect to a criterion. For example, a good approximation of product cost is the number of parts in a design. Similarly, a good approximation of manufacturing leadtime is the number of operations or processes required to produce a product. The use of the objective metrics will help us minimize the judgmental nature of the evaluating process.

4. A FRAMEWORK OF FUZZY ANALYTIC HIERARCHY PROCESS

In the proposed approach, the integration of fuzzy theory and analytic hierarchy process is employed. Figure 3 shows the structure of the intended decision problem.

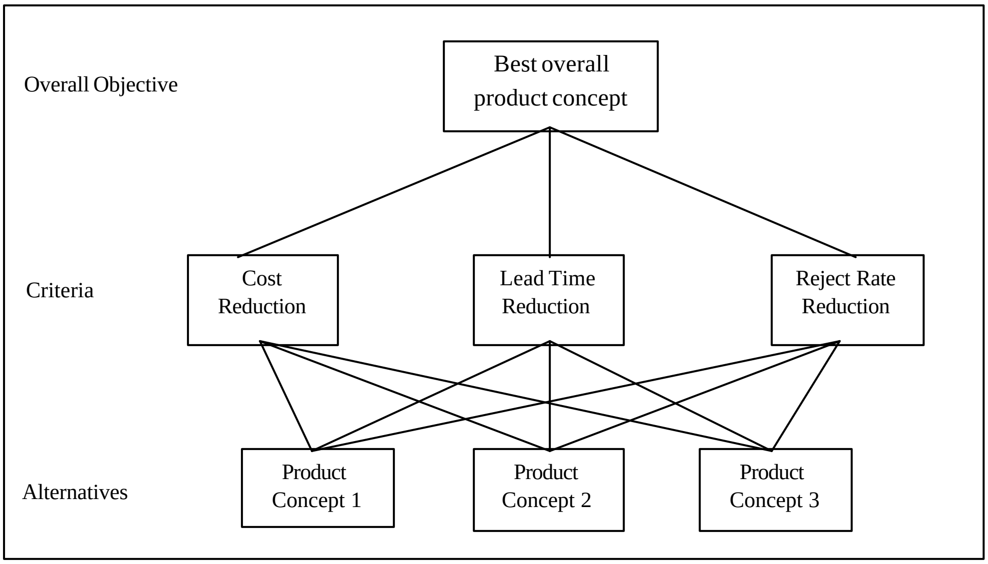


Figure 3. The Decision Hierarchy of Product Concept Selection

The first level is the overall objective of the decision problem. The second level is a list of criteria to be considered in achieving the overall objective. The third level is the set of alternatives to be evaluated using the AHP methodology. For simplicity, there are only three product concepts, A_1, A_2, A_3 and three criteria, *Cost Reduction, Lead Time Reduction, Reject Rate Reduction* to be considered.

4.1 The Mechanic of AHP with a Reference

In this approach, a reference is used in performing pairwise comparison in an effort to achieve consistency. The pairwise comparison matrix between a product concept and a reference with respect to criteria (*CR* = Cost Reduction, *LTR*=Lead Time Reduction, and *RRR* = Reject Rate Reduction) is shown in the following table:

	Concept 1	Concept 2	Concept 3
CR	$a_{1,C}$	$a_{2,C}$	$a_{3,C}$
LTR	$a_{1,L}$	$a_{2,L}$	$a_{3,L}$
RRR	$a_{1,R}$	$a_{2,R}$	$a_{3,R}$

Matrix 1

The corresponding original AHP's pairwise comparison matrices are:

	Concept 1	Concept 2	Concept 3
Concept 1	$a_{1,C}/a_{1,C}$	$a_{1,C}/a_{2,C}$	$a_{1,C}/a_{3,C}$
Concept 2	$a_{2,C}/a_{1,C}$	$a_{2,C}/a_{2,C}$	$a_{2,C}/a_{3,C}$
Concept 3	$a_{3,C}/a_{1,C}$	$a_{3,C}/a_{2,C}$	$a_{3,C}/a_{3,C}$

Matrix 1a

	Concept 1	Concept 2	Concept 3
Concept 1	$a_{1,L}/a_{1,L}$	$a_{1,L}/a_{2,L}$	$a_{1,L}/a_{3,L}$
Concept 2	$a_{2,L}/a_{1,L}$	$a_{2,L}/a_{2,L}$	$a_{2,L}/a_{3,L}$
Concept 3	$a_{3,L}/a_{1,L}$	$a_{3,L}/a_{2,L}$	$a_{3,L}/a_{3,L}$

Matrix 1b

	Concept 1	Concept 2	Concept 3
Concept 1	$a_{1,R}/a_{1,R}$	$a_{1,R}/a_{2,R}$	$a_{1,R}/a_{3,R}$
Concept 2	$a_{2,R}/a_{1,R}$	$a_{2,R}/a_{2,R}$	$a_{2,R}/a_{3,R}$
Concept 3	$a_{3,R}/a_{1,R}$	$a_{3,R}/a_{2,R}$	$a_{3,R}/a_{3,R}$

Matrix 1c

The relative weight of criteria with respect to the overall objective is *CR: LTR: RRR = w1: w2: w3*. The corresponding original AHP's pairwise comparison matrix is:

	CR	LTR	RRR
CR	w_1/w_1	w_1/w_2	w_1/w_3
LTR	w_2/w_1	w_2/w_2	w_2/w_3
RRR	w_3/w_1	w_3/w_2	w_3/w_3

Matrix 2

Once the pairwise comparison matrices such as Matrix 1 and Matrix 2 are built, the relative weight of each alternative with respect to criteria and the relative weight of each criterion on the overall objective can be calculated through use of a technique suggested by (Saaty, 1977, 1980, 1982). A method of computing vectors of relative weight is in *Appendix A* The aggregation process for obtaining the concept priority can be done through use of the following matrix operation:

	Normalized Cost Reduction Relative to Reference's	Normalized Lead Time Reduction Relative to Reference's	Normalized Reject Rate Reduction Relative to Reference's		Vector relative weight of criteria		Normalized Priorities
Concept 1	$a_{1,C}/(a_{1,C}+a_{2,C}+a_{3,C})$	$a_{1,L}/(a_{1,L}+a_{2,L}+a_{3,L})$	$a_{1,R}/(a_{1,R}+a_{2,R}+a_{3,R})$		$w_1/(w_1+w_2+w_3)$		X_1
Concept 2	$a_{2,C}/(a_{1,C}+a_{2,C}+a_{3,C})$	$a_{2,L}/(a_{1,L}+a_{2,L}+a_{3,L})$	$a_{2,R}/(a_{1,R}+a_{2,R}+a_{3,R})$	X	$w_2/(w_1+w_2+w_3)$	=	X_2
Concept 3	$a_{3,C}/(a_{1,C}+a_{2,C}+a_{3,C})$	$a_{3,L}/(a_{1,L}+a_{2,L}+a_{3,L})$	$a_{3,R}/(a_{1,R}+a_{2,R}+a_{3,R})$		$w_3/(w_1+w_2+w_3)$		X_3

4.2 The Mechanic of Fuzzy AHP with a Reference

Fuzzy AHP accommodates impreciseness of the product concept at the preliminary design stage. The assigned values in previous matrix 1 and matrix 2 are represented in terms of fuzzy numbers, in this case triangular fuzzy numbers.

For example: Concept 1's Cost Reduction relative to the Reference in matrix 1 that is $a_{1,C}$ is represented by $\mathbf{A}_{1,C}$

$$\mathbf{A}_{1,C} \equiv m_{\mathbf{A}}(x) = \begin{cases} 2\dfrac{x-c_1}{c_2-c_1} & \text{for } c_1 \le x \le \dfrac{c_1-c_2}{2} \\[2ex] 2\dfrac{x-c_2}{c_1-c_2} & \text{for } \dfrac{c_1-c_2}{2} \le x \le c_2 \\[2ex] 0 & \text{otherwise} \end{cases}$$

by substituting *c1*, *c2* with values of 4 and 5, respectively, we will get the following fuzzy membership function :

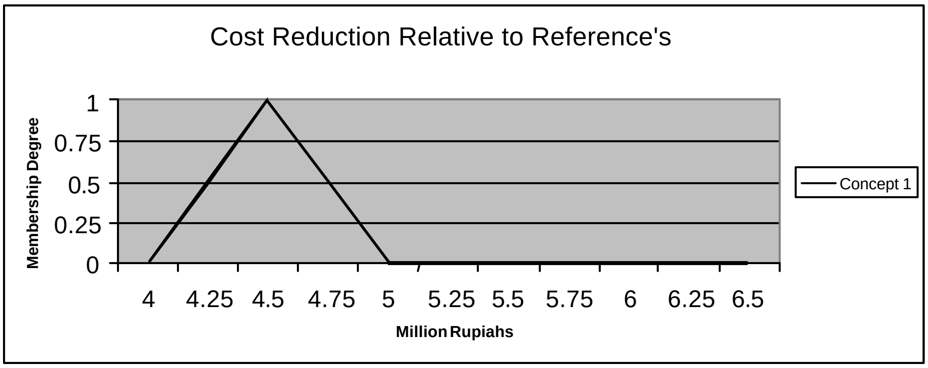


Figure 4. Fuzzy Membership Function

To calculate the concept priority through matrix operation as described in AHP with a reference, an interval arithmetic is used. A fuzzy number can be represented as a series of intervals for every λ cut. λ cut of a fuzzy set is defined as a crisp interval for a particular degree of membership, α. α can take values between 0 and 1.

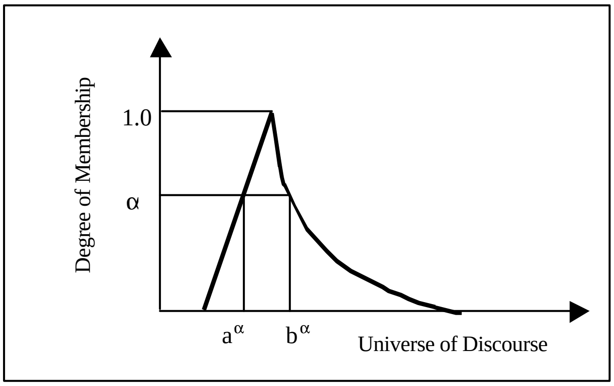


Figure 5. Interval Arithmetic for Fuzzy Operations

For any two intervals [a,b] and [d,e], the arithmetic operations are performed in the following way:

Addition : [a,b] + [d,e] = [a+d, b+e]

Multiplication : [a,b] . [d,e] = [min(ad,ae,bd,be), max(ad,ae,bd,be)]

Division : [a,b]/[d,e] = [min(a/d,a/e,b/d,b/e), max(a/d,a/e,b/d,b/e)]

5. A NUMERICAL EXAMPLE

5.1 Analytic Hierarchy Process with a Reference

To describe the procedure, we give a typical example of product development problem. Suppose we are having three product concepts. We want to come up with priorities among the concepts with respect to three factors: *cost, lead time* and *reject rate*. Those factors are compared with a reference, so we can get a relative values describing three criteria: *cost reduction* (relative to reference's cost), *lead time reduction* (relative to reference's lead time) and *reject rate reduction* (relative to reference's reject rate reduction). The table below shows a numerical example produced by an expert:

Criteria (metric)	Concept 1	Concept 2	Concept 3
Cost reduction (million rupiahs)	4.5	6	5
Lead time reduction (days)	18	4	10
Reject rate reduction (%)	5	4	7

If we use the original AHP, the corresponding consistent pairwise comparison matrices based on the above information are:

Cost reduction	Concept 1	Concept 2	Concept 3
Concept 1	1.00	0.75	0.90
Concept 2	1.33	1.00	1.20
Concept 3	1.11	0.83	1.00

Lead time reduction	Concept 1	Concept 2	Concept 3
Concept 1	1.00	4.50	1.80
Concept 2	0.22	1.00	0.40
Concept 3	0.56	2.50	1.00

Reject rate reduction	Concept 1	Concept 2	Concept 3
Concept 1	1.00	1.25	0.71
Concept 2	0.80	1.00	0.57
Concept 3	1.40	1.75	1.00

Based on an expert knowledge we can describe the relative weight of criteria on the overall objective. The overall objective is maximizing shareholder's value proxied by present worth. Suppose the relative weight of *Cost Reduction, Lead Time Reduction, and Reject Rate Reduction* on Present Worth are 4, 2, and 1 respectively, then a 1% change in Cost Reduction results in 4% change in Present Worth, a 1% change in Lead Time Reduction will result in 2% change in Present Worth and so on.

The consistent pairwise comparison matrix is shown below.

	CR	LTR	RRR
Cost reduction (CR)	1.00	2.00	4.00
Lead time reduction (LTR)	0.50	1.00	2.00
Reject rate reduction (RRR)	0.25	0.50	1.00

5.2 Aggregation process

Using the above information we can calculate the priorities summarized in the table below:

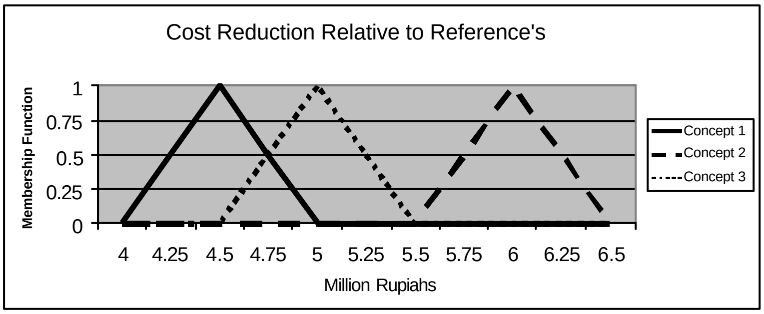
	Normalized Cost Reduction Relative to Reference's	Normalized Lead Time Reduction Relative to Reference's	Normalized Reject Rate Reduction Relative to Reference's	Vector relative weight of criteria	Normalized Priorities
Concept 1	0.290	0.563	0.313	0.571	0.371
Concept 2	0.387	0.125	0.250	0.286	0.293
Concept 3	0.323	0.313	0.438	0.143	0.336

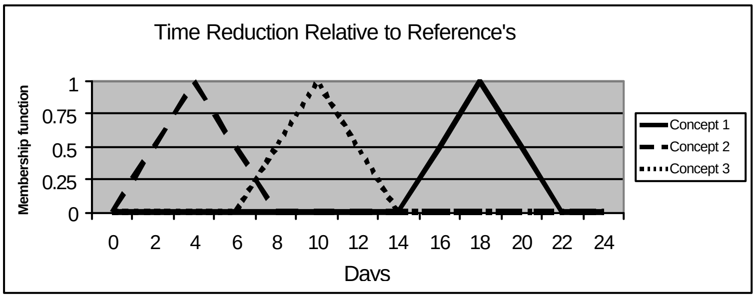
From the table above, it is obtained that Concept 1 has the highest priority followed by Concept 3 and Concept 2.

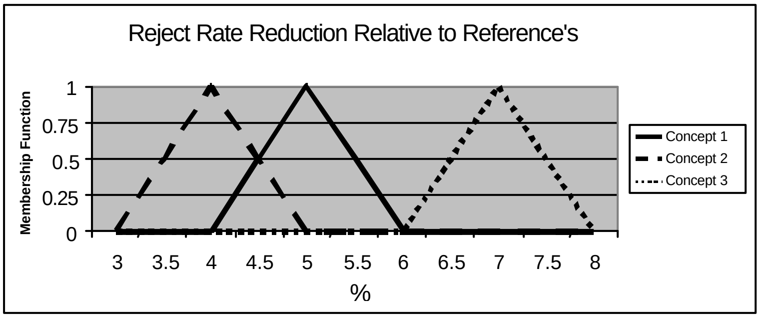
5.3 Fuzzy Analytic Hierarchy Process with a Reference

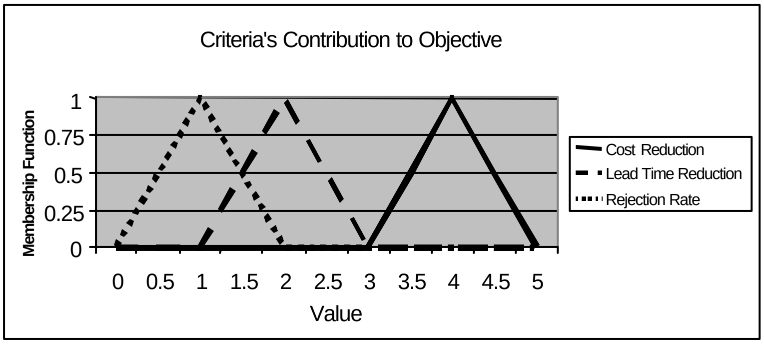
We have already discussed an expert knowledge in determining the numbers that compare alternatives and criteria. By nature, that knowledge is imprecise. So we develop a fuzzy AHP with a reference that accommodates the impreciseness. In this approach, fuzzy numbers are used to describe the assigned values instead of crisp numbers.

Suppose the fuzzy membership functions of an expert knowledge are all triangles and are shown in the following figures:



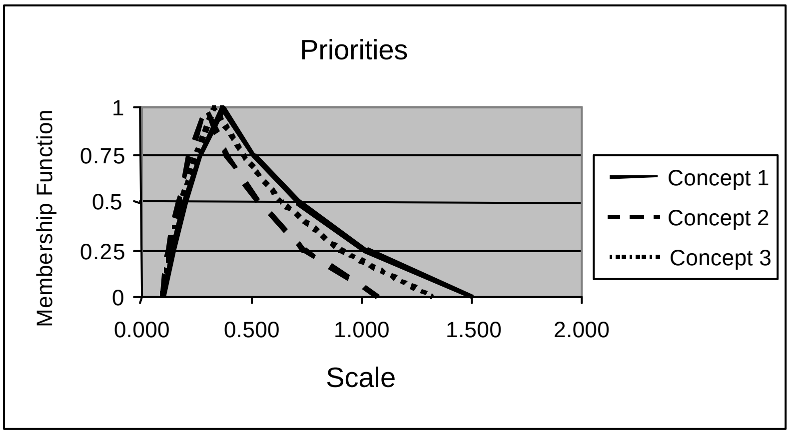






To calculate priorities between concepts, we use the fuzzy arithmetic of addition, multiplication and division. The result is consistent with Analytical Hierarchy Process with a reference that we have already discussed in the previous section. The fuzzy numbers describing the priorities are shown the following table and figure:

á	0	0.25	0.5	0.75	**1**	0.75	0.5	0.25	0
Concept 1	0.102	0.143	0.197	0.270	**0.371**	0.513	0.717	1.022	1.502
Concept 2	0.097	0.127	0.167	0.220	**0.293**	0.393	0.536	0.747	1.073
Concept 3	0.093	0.130	0.179	0.246	**0.336**	0.462	0.642	0.909	1.324



Again, the table above assigns Concept 1 the highest priority, followed by Concept 3 and Concept 2. These results are consistent with those obtained from the original AHP. Interestingly, the values of priorities for each concept obtained from the original AHP are the same with those obtained from fuzzy AHP with $a=1$.

6. CONCLUSION

A fuzzy-based decision making integrating fuzzy theory and AHP for product concept selection has been proposed and discussed. Unlike the original AHP, the proposed approach uses the fuzzy membership function and a reference when performing pairwise comparisons. This is due to the impreciseness of product concepts at the preliminary design stage. A numerical example is also presented and the results show that the fuzzy AHP gives the same ranking order as the original AHP does. Major advantages of using this fuzzy AHP with a reference are the following: (1) it can accommodate the impreciseness of product concept at the preliminary design stage, (2) the result is also a fuzzy number which resembles natural human thinking when comparing alternatives. Despite those advantages, some difficulties might be encountered and need to be further investigated. One of difficulties is perhaps in absorbing an expert knowledge and represents it in terms of fuzzy numbers. Also, a further investigation needs to be done to see whether or not using different fuzzy numbers will give the same result as the original AHP does.

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