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GREEN CONCEPT EVALUATION THROUGH FUZZY AHP-PROMETHEE II

Abstract:

The demand for green products have dramatically increased because the importance and public awareness of the preservation of natural environment was taken into consideration much more last two decades. As a result of this, especially manufacturing companies have been forced to design more green products, resulting in a problem of how they incorporate environmental issues into their design and evaluate concept options. The need for the practical decision making tools to address this problem is rapidly evolving due to the fact that the problem turns into a multiple-criteria decision making (MCDM) problem in the presence of a set of green concept alternatives and criteria. Therefore; in this paper, the four popular MCDM methods in fuzzy environment are utilized to reflect the vagueness and uncertainty on the judgments of DMs, because the crisp pairwise comparison in these conventional MCDM methods seems to be insufficient and imprecise to capture the right judgments of DMs. Of these methods; as Fuzzy AHP is used to calculate criteria weights, the other method; Fuzzy PROMETHEE II is used to rank alternatives. Furthermore, the incorporation of fuzzy set theory into these methods is discussed on a real-life case study.

Keywords:

New product development, green concept selection, multiple-criteria decision making, fuzzy logic, AHP, PROMETHEE II

JEL Classification: C44, C00, D81

1. Introduction

Designing green products as the result of raising demand from public awareness of the preservation of natural environment have become a critical concern for companies, incorporating environmental issues in their product design according to meeting recent green guidelines. For companies to follow these guidelines in their new product development environment has to be carried out with special procedures. A NPD process is the sequence of steps or activities which an enterprise employs to conceive, design and commercialize a product (Ulrich and Eppinger, 2000). This process has the following activities with environmental issues from raw materials, production, transportation and distribution to re-use, remanufacturing, recycling to final disposal (Zhang *et al.*, 1997); (a) identifying customer needs, (b) establishing target specifications, (b) concept generation, (d) concept selection, (e) concept testing, (f) setting final specifications, (g) project planning, (h) economic analysis, (i) benchmarking of competitive products, (j) modeling and (k) prototyping.

Among these activities; *the concept selection* is a process of evaluating a set of concept alternatives in terms of the criteria (i.e. quality level and unit cost) to find out the best option (Ayag, 2005a; 2005b). It is also critical because the selected concept plays important role at the phase of generating a set of the design alternatives. On the other hand, it is pointed out in literature that around 70% of the unit cost of a product is committed at this phase (Duffy *et al.*, 1993). After this, the development process will lead to a more detailed solution. Therefore, the concept selection is shortly defined to evaluate a set of design alternatives in a new product environment, and also a critical element to improve design productivity. In addition, during the development process, a company's product engineers (or designers) have to consider an increased number of design options to meet the needs of customers. The activity of judging and selecting from a set of competing design options is referred to as *evaluation*. As the number of design options to evaluate increases and the time available decreases, it is clear that designers or product engineers needs more help evaluate the possible concept alternatives and determine the most satisfying one. So, the evaluation process can be defined as a multiple-criteria decision making (MCDM) problem due to the fact that there are a set of alternatives which should be evaluated in terms of evaluation criteria, and a decision-maker(s) (DMs) will need at least one of MCDM methods in current literature. Therefore; in this paper, the two popular MCDM methods are chosen for the evaluation design alternatives, such as *Analytic* Hierarchy Process (AHP) invented by Thomas L. Saaty (Saaty, 1981) and PROMETHEE II (Preference Ranking Organization Method for Enrichment Evaluations) by Jean-Pierre Brans (Brans *et al.*, 1986).

On the other hand, these conventional MCDM methods use a crisp scale to reach the best satisfying alternative. As result of this, some shortcomings are observed as follows: it causes unbalanced scale of the judgments of a DM, does not model the uncertainty by mapping of DM's judgment to a number, the subjective judgment of a DM has great influence on the ranking. Due to the vagueness and uncertainty on the judgments of a

DM, the crisp comparison in these conventional methods seems to be insufficient and imprecise to capture the right judgments of DMs. That's why that, in this study, fuzzy logic is utilized to make up for this deficiency in the conventional methods.

Shortly, the objective of this paper is to propose a fuzzy AHP (F-AHP) based approach to green concept evaluation problem through Fuzzy PROMETHEE II (F-PROMETHEE II) methods. Of these methods; as F-AHP is used to calculate criteria weights, the other; F- PROMETHEE II are used to rank alternatives. The integration of fuzzy set theory into the two methods is discussed on a real-life case study.

2. Proposed approach

Designing a green product or components in a new product development (NPD) environment is a comprehensive process because the process is progressively detailed through a series of phases. At the end of each phase called generally "the gate"; a design review is held to approve the design and release it to the next level. In this paper, as one of the critical phases of the NPD process, the phase of concept selection is taken into consideration to evaluate green concept alternatives in order to find out the most appropriate green concept for further development activities. On the other hand, the selecting process for the best concept becomes so vital and complicated for companies because, as the development progresses on a selected concept, it becomes more difficult to make any design modifications because of quality, cost and schedule implications. Therefore, to facilitate to find out the best green concept alternative among a set of alternatives, in this paper, a fuzzy AHP-based F-PROMETHEE II is proposed to firstly weight the evaluation criteria though F-AHP, and rank concept alternatives using F- PROMETHEE II. Next, this approach with three sections are explained more in detail.

2.1 Criteria weighting through F-AHP

The main idea of fuzzy set theory developed by Zadeh is based on an element with a degree of membership in a fuzzy set (Zadeh, 1965), which is defined by a membership function mapping elements in the universe of discourse to elements in a certain interval of $[0, 1]$.

In the first section, the AHP is used for weighting a set of criteria using a nine-point scale, and based on a hierarchy considering the distribution of a goal amongst the elements being compared, and judges which element has a greater influence on that goal. It is one of the most commonly used MCDM methods, in literature and has been widely used for different kinds of MCDM problems (Ayag and Ozdemir, 2007). For weighting the evaluation criteria for green concept selection problem using F-AHP, triangular fuzzy numbers (TFNs), $\tilde{1}$ to $\tilde{9}$, are utilized to make the required pairwise comparisons of selection process to capture the vagueness of a DM.

A fuzzy number is a special fuzzy set $F = \{(x, \mu_F(x)), x \in R\}$, where x takes its values on the real line, $R: -\infty < x < +\infty$ and $\mu_F(x)$ is a continuous mapping from R to the closed interval $[0, 1]$. A TFN denoted as $\tilde{M} = (l, m, u)$, where $l \leq m \leq u$, has the following triangular type membership function. The TFNs are used to improve the traditional the nine-point scaling scheme of Saaty's to take the imprecision and vagueness of a DM judgments into consideration. In this scale; the five TFNs ($\tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9}$) are defined with their membership function. All evaluation criteria and alternatives are linguistically. The shape and position of linguistically elements are chosen to illustrate the fuzzy extension of the method.

Later, the DM is asked to compare the elements at a given level on a pairwise basis to estimate their relative importance in relation to the element at the immediate preceding level. In traditional AHP of Saaty, the required pairwise comparisons are done by using a nine-point ratio scale (Saaty, 1989). Unfortunately, although this scale has the advantages of simplicity and easiness, it is not enough to reflect the uncertainty in associated with the mapping of DM's judgment to a number. Therefore, the fuzzy logic is integrated to the conventional AHP to overcome this difficulty, called *F-AHP*. Next, the steps of this method is concisely given;

Step 1. Comparing the performance scores: the TFNs are used to indicate the relative strength of each pair of elements in the same hierarchy.

Step 2. Constructing the fuzzy comparison matrix: the fuzzy judgment matrix $\tilde{A} (a_{ij})$ is constructed via pairwise comparison using TFNs as given below;

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \dots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \dots & \dots & \tilde{a}_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \dots & \dots & 1 \end{bmatrix}$$

where, $\tilde{a}_{ij}^\alpha = 1$, if i is equal j , and $\tilde{a}_{ij}^\alpha = \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9}$ or $\tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1}$, if i is not equal j

Step 3. Solving fuzzy eigenvalue: A fuzzy eigenvalue, $\tilde{\lambda}$ is a fuzzy number solution to $\tilde{A}x = \tilde{\lambda}x$ (Eq.1), where is $n \times n$ fuzzy matrix containing fuzzy numbers \tilde{a}_{ij} and x is a non-zero $n \times 1$, fuzzy vector containing fuzzy number \tilde{x}_i . To perform fuzzy multiplications and additions by using the interval arithmetic and α -cut, the equation $\tilde{A}x = \tilde{\lambda}x$ is equivalent to

$$\begin{aligned}
 & [a_{i1l}^\alpha x_{1l}^\alpha, a_{i1u}^\alpha x_{1u}^\alpha] \oplus \dots \oplus [a_{inl}^\alpha x_{nl}^\alpha, a_{inu}^\alpha x_{nu}^\alpha] = [\lambda x_{il}^\alpha, \lambda x_{iu}^\alpha] \quad \text{where,} \quad \tilde{A} = \begin{bmatrix} \tilde{a}_{11} \\ \tilde{a}_{12} \\ \vdots \\ \tilde{a}_{ij} \\ \vdots \\ \tilde{a}_{in} \end{bmatrix}, x^t \\
 & = \left(\tilde{x}_1, \dots, \tilde{x}_n \right), \tilde{a}_{ij}^\alpha = [a_{ijl}^\alpha, a_{iju}^\alpha], x_i^\alpha = [x_{il}^\alpha, x_{iu}^\alpha], \tilde{\lambda}^\alpha = [\lambda_l^\alpha, \lambda_u^\alpha] \text{ for } 0 < \alpha \leq 1 \text{ and all } i, j, \text{ where } i=1, \\
 & 2 \dots n, j=1, 2 \dots n \text{ (Eq.2)}
 \end{aligned}$$

α -cut is commonly known to incorporate a DM confidence over his/her judgments. The degree of satisfaction for a judgment matrix; \tilde{A} is estimated by using the index of optimism μ . The larger value of index μ indicates the higher degree of optimism. The index of optimism is a linear convex combination defined by Lee (1999) and given as the following equation: $\tilde{a}_{ij}^\alpha = \mu a_{iju}^\alpha + (1 - \mu) a_{ijl}^\alpha, \quad \forall \mu \in [0,1]$ (Eq.3) while α is fixed, the following matrix is obtained after setting the value of μ , to estimate the degree of satisfaction.

$$\tilde{A} = \begin{bmatrix} 1 & \tilde{a}_{12} & \dots & \dots & \tilde{a}_{1n}^\alpha \\ \tilde{a}_{21}^\alpha & 1 & \dots & \dots & \tilde{a}_{2n}^\alpha \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{a}_{n1}^\alpha & \tilde{a}_{n2}^\alpha & \dots & \dots & 1 \end{bmatrix}$$

The eigenvector is calculated by fixing the μ value and identifying the maximal eigenvalue. Then, the matrix is normalized and the priority weights of the concept alternatives are determined.

Step 4. Consistency analysis; To make sure that the result is based on the consistent on the judgments of the DM, first λ_{\max} calculated by Eq.(1), then the consistency index (CI) is calculated for the matrix by Eq.(4). The deviations from the consistency are expressed by the CI; the measure of inconsistency;

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad \text{(Eq.4)}$$

Later, the consistency ratio (CR) is calculated by Eq. (5) by dividing the value of CI by the value from the table of *Random Consistency Index (RI)*, the average index for randomly generated weights based on the matrix size (Saaty, 1981);

$$CR = \frac{CI}{RI} \quad \text{(Eq.5)}.$$

For consistency for a matrix, the value of CR should be less than 0.10, and it means that the pairwise comparisons of the DM are consistent and acceptable, otherwise not.

2.2 Ranking alternatives through the three F-PROMETHEE II

In literature; it is reported that the PROMETHEE II has been used with success to solve various MCDM problems (Samanlioglu and Ayag, 2016). It is based on a comparison pair per pair of possible decisions along each criterion. Possible decisions are evaluated according to different criteria, which have to be maximized or minimized. It also requires two additional types of information for each criterion; a *weight* and a *preference function*. The preference function characterizes the difference for a criterion between the evaluations obtained by two possible decisions into a preference degree in the interval of [0, 1]. To facilitate the definition of these functions, six basic preference functions were proposed by Figueira *et. al.* (2004). Next, the four steps of F-PROMETHEE II are presented (Samanlioglu and Ayağ, 2016);

Step 1. Construct a fuzzy decision making matrix together with the results of the F-AHP method; $W = (w_1, w_2, w_3, \dots, w_n)$, where $\sum w_i = 1$ ($i = 1, 2, \dots, n$), and a typical m by n fuzzy decision matrix is shown as below;

$$\begin{array}{c} (w_1 \dots w_j \dots w_n) \\ (\hat{c}_1 \dots \hat{c}_j \dots \hat{c}_n) \\ \hat{A}_1 \\ \cdot \\ \hat{A}_i \\ \cdot \\ \hat{A}_m \end{array} \begin{bmatrix} 1 & \tilde{r}_{12} & \dots & \dots & \tilde{r}_{1n} \\ \tilde{r}_{21} & 1 & \dots & \dots & \tilde{r}_{2n} \\ \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots \\ \tilde{r}_{m1} & \tilde{r}_{m2} & \dots & \dots & 1 \end{bmatrix}$$

Here, $\hat{c}_j \in \hat{C}$ is a fuzzy positive criterion. The criterion is a maximum criterion, if the DM prefers more value for it. Otherwise, it is a minimum. $\hat{A}_i \in \hat{A}$ is fuzzy alternative. \hat{A}^* is the fuzzy alternative from \hat{A} . $\hat{r}_{ij} \in \hat{r}$ is the utility value. $w_j \in W$ is the weight of \hat{c}_j .

Step 2. Index fuzzy numbers in the fuzzy decision matrix: the fuzzy number in the fuzzy matrix is defuzzified with *centroid defuzzification approach* (Wang, 2009) to the crisp number by Eq. (6);

$$(l, m, u) = (l + m + u)/3 \quad (\text{Eq.6})$$

In other words, the above process converts a fuzzy decision matrix into a crisp decision matrix as follows:

$$\begin{array}{c} (w_1 \dots w_j \dots w_n) \\ (c_1 \dots c_j \dots c_n) \\ A_1 \left[\begin{array}{cccc} 1 & r_{12} & \dots & r_{1n} \\ \vdots & r_{21} & 1 & \dots & r_{2n} \\ \vdots & \dots & \dots & \dots & \dots \\ A_i & \dots & \dots & \dots & \dots \\ \vdots & \dots & \dots & \dots & \dots \\ A_m & r_{m1} & r_{m2} & \dots & 1 \end{array} \right] \end{array}$$

where, $c_j \in C$ is the positive criterion, $A_i \in A$ is the alternative, A^* is the ideal alternative from A , $r_{ij} \in r$ is the utility value, $w_j \in W$ is the weight of c_j . The cap removal from the notations is crisp value.

Step 3. Calculate aggregated preference indices: $P_j(A_i, A_k) = P_j(d(A_i, A_k)) = P_j(r_{ij} - r_{kj})$ is a preference function showing how much A_i prefers to A_k with respect to c_j . Brans *et al.* (1984) defined the six types of generalized functions, and also pointed out that the *Gaussian criterion* rather than the others was mostly preferred by users for practical applications especially in the case of continuing data. Due to the fact that the evaluation criteria contain continuing data, the *Gaussian criterion* preference function was chosen here for the evaluation process as given as follows:

$$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d > 0 \end{cases}, \quad (\text{Eq.7})$$

if the criterion is a maximum and

$$P(d) = \begin{cases} 0 & d \geq 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d < 0 \end{cases} \quad (\text{Eq.8})$$

if the criterion is a minimum.

Aggregated preference index $\pi(A_i, A_k)$ expresses the degree of how much A_i is preferred to A_k over all the criteria. The aggregated preference indices are of the form:

$$\pi(A_i, A_k) = \frac{\sum_{j=1}^n P_j(A_i, A_k) \cdot w_j}{\sum_{j=1}^n w_j}, \forall A_i, A_k \in A \text{ and } i \neq k \quad (\text{Eq.9})$$

Step 4. Calculate outranking flow. Each alternative A_i is facing $(m-1)$ other alternatives in A . In order to rank the alternatives, the outranking flows are defined as follows:

The positive outranking flow is of the form:

$$\phi^+(A_i) = \sum_{k=1}^m \pi(A_i, A_k) \quad (\text{Eq. 10})$$

The negative outranking flow is of the form:

$$\phi^-(A_i) = \sum_{k=1}^m \pi(A_k, A_i) \quad (\text{Eq.11})$$

The net outranking flow is applied and is in the form of:

$$\phi(A_i) = \phi^+(A_i) - \phi^-(A_i), \forall i \in \{1, \dots, m\} \quad (\text{Eq.12})$$

The positive outranking flow expresses how an alternative A_i is outranking all the others. Higher $\phi^+(A_i)$ gives a better alternative. On the other hand, the negative outranking flow expresses how an alternative A_i is outranked by all the others. The lower $\phi^-(A_i)$ gives a better alternative. The higher $\phi(A_i)$ specifies the final better alternative.

3. Case study

In the previous section, a F-AHP-based F-PROMETHEE II has been presented to evaluate a set of green conceptual design alternatives in terms of the evaluation criteria in a NPD environment. In this section, a case study is presented for potential readers or practitioners to clearly explain of how the comparative approach works on a real-life case. For this purpose; the case study is constructed by inspiring from a study previously done in a hot runner system manufacturer in Canada (Ayag, 2014). This case study has

the four different concepts, named; *Concept A, B, C* and *D* respectively, together with the four-evaluation criteria as given in table 1, three of which were determined by utilizing the previous study, last one; *green criterion* was newly-added by taking the principles of *Design for Environment (DfE)* into consideration in order to obtain environmental-friendly products, which are so vital and expected by most of mold-manufacturers in today's business world.

Table 1: List of criteria for the green concept selection problem

Code	Criteria	Definition
C	Cost	Development cost, unit manufacturing cost
R	Risk	Envisioning risk, design risk, execution risk, on-time delivery
Q	Quality	Product quality, cycle time, quick color change, precision, flexibility, conductivity, strength, resistance, repeatability and reproducibility
G	Green	Environmental friendly materials and production, amount of recycling content, environmental friendly use of product and sustainable packaging, disposability at the end of the product life

3.1 Determining weights of the criteria through F-AHP

Firstly, after weighting the four-evaluation criteria; *cost, risk, quality, and green*, the details of which are given in table 3, the TFNs $(\tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9})$ are used to express the preference in the pairwise comparisons, and the fuzzy pair-wise comparison matrix (\tilde{A}) for the relative importance of the criteria is constructed as given in table 2.

Table 2: Fuzzy comparison matrix of the criteria using TFNs

Criteria	Cost	Risk	Quality	Green
Cost	1	$\tilde{3}$	$\tilde{9}$	$\tilde{9}$
Risk	$\tilde{3}^{-1}$	1	$\tilde{3}$	$\tilde{7}$
Quality	$\tilde{9}^{-1}$	$\tilde{3}^{-1}$	1	$\tilde{1}$
Green	$\tilde{9}^{-1}$	$\tilde{7}^{-1}$	$\tilde{1}^{-1}$	1

Secondly, the lower and upper limits of the fuzzy numbers in the fuzzy matrix (\tilde{A}) , with respect to α , the confidence level are defined by applying Eq. (2) as follows:

$$\begin{aligned}\tilde{1}_\alpha &= [1, 3 - 2\alpha], \tilde{3}_\alpha = [1 + 2\alpha, 5 - 2\alpha], \tilde{3}_\alpha^{-1} = \left[\frac{1}{5 - 2\alpha}, \frac{1}{1 + 2\alpha} \right], \tilde{5}_\alpha = [3 + 2\alpha, 7 - 2\alpha], \\ \tilde{5}_\alpha^{-1} &= \left[\frac{1}{7 - 2\alpha}, \frac{1}{3 + 2\alpha} \right], \tilde{7}_\alpha = [5 + 2\alpha, 9 - 2\alpha], \tilde{7}_\alpha^{-1} = \left[\frac{1}{9 - 2\alpha}, \frac{1}{5 + 2\alpha} \right], \\ \tilde{9}_\alpha &= [7 + 2\alpha, 11 - 2\alpha], \tilde{9}_\alpha^{-1} = \left[\frac{1}{11 - 2\alpha}, \frac{1}{7 + 2\alpha} \right]\end{aligned}$$

Then, the values of $\alpha = 0.5$ and $\mu = 0.5$ were determined using the interval of [0-1] by the DM, who works as a design engineer at the company, are substituted, where μ indicates the coefficient of optimism, above expression into the fuzzy comparison matrix, and the α -cuts fuzzy comparison matrix is obtained by Eq. (3) as presented in table 3.

Table 3: α -cuts fuzzy comparison matrix for the criteria ($\alpha = 0.5, \mu = 0.5$)

Criteria	Cost	Risk	Quality	Green
Cost	1	[2, 4]	[8, 10]	[8, 10]
Risk	[1/4, 1/2]	1	[2, 4]	[6, 8]
Quality	[1/10, 1/8]	[1/4, 1/2]	1	[1, 2]
Green	[1/10, 1/8]	[1/8, 1/6]	[1/2, 1]	1

Later, the eigenvalue of the matrix A is calculated by solving the characteristic equation of $A, \det(A - \lambda I) = 0$, and found out all λ values for A ($\lambda_1, \lambda_2, \lambda_3$). Next, the largest eigenvalue of pairwise matrix, λ_{\max} , is calculated by using Eq. (1), where the matrix size, n is 4, and the $RI(4)$ is 1.12. Finally, the CI and the CR of the matrix A are calculated by Eq. (4) and Eq. (5) and given in table 4. As seen in table, the CR value, 0.052 is less than to 0.10, and it means that all the pairwise comparisons of the DM are consistent. As also seen in the far right column of the table, the e-Vector of the criteria weights as crisp values are respectively as follows; $W = (0.607, 0.263, 0.077, 0.053)$.

Table 4: Eigenvector for comparison matrix of the criteria (CR =0.052)

Criteria	Cost	Risk	Quality	Green	
Cost	1.000	3.000	9.000	9.000	0.607
Risk	0.375	1.000	3.000	7.000	0.263
Quality	0.113	0.375	1.000	1.500	0.077
Green	0.113	0.146	0.750	1.000	0.053
				λ_{max}	4.174
				<i>CI</i>	0.058
				<i>RI</i>	1.12
				<i>CR</i>	0.052

3.2 Ranking green concept alternatives using F-PROMETHEE II

In the previous section, the relative weights of the evaluation criteria are determined, and next, the fuzzy PROMETHEE II for ranking green concept alternatives are implement;

First, the vector of criteria weights (W) and fuzzy decision matrix (\tilde{X}) are given to the alternatives with respect to all the criteria; *cost*, *risk*, *quality*, and *green* as shown in table 6. Moreover, the values of s in the table indicate maximum due to the fact that each criterion is maximum with the value of s ; being equals to 5. For example: If the alternatives; *Concept A*, *Concept B*, *Concept C*, and *Concept D* are evaluated in terms of the criterion; *Cost*, using the TFNs, the fuzzy values; $\{(7.0, 8.0, 9.0), (4.0, 5.0, 6.0), (2.0, 3.5, 5.0), (1.0, 2.0, 3.0)\}$ are obtained respectively.

Later, the fuzzy decision matrix is converted into crisp decision matrix by Eq. (6) as shown in table 7. With respect to the crisp decision matrix in table 6, the aggregated preference matrix for $P1$ (*Concept A*, *Concept B*) is shown in table 7.

Table 6: Fuzzy decision matrix for the green concept selection for F-PROMETHEE II

Criteria	Cost	Risk	Quality	Green
Value	Max.	Max.	Max.	Max.
s	5	5	5	5
Weight	0.607	0.263	0.077	0.053
Concept A	(7.0, 8.0, 9.0)	(2.0, 3.5, 5.0)	(2.0, 3.5, 5.0)	(5.0, 6.5, 8.0)
Concept B	(4.0, 5.0, 6.0)	(4.0, 5.0, 6.0)	(1.0, 2.0, 3.0)	(8.0, 9.0, 10.0)
Concept	(2.0, 3.5, 5.0)	(8.0, 9.0,	(5.0, 6.5, 8.0)	(7.0, 8.0, 9.0)
Concept	(1.0, 2.0, 3.0)	(2.0, 3.5, 5.0)	(4.0, 5.0, 6.0)	(2.0, 3.5, 5.0)

Table 7: Decision making matrix after indexing

Criteria Value s	Cost Max. 5	Risk Max. 5	Quality Max. 5	Green Max. 5
Weight	0.607	0.263	0.077	0.053
Concept A	8.000	3.500	3.500	6.500
Concept B	5.000	5.000	2.000	9.000
Concept C	3.500	9.000	6.500	8.000
Concept D	2.000	3.500	5.000	3.500

The *Gaussian criterion* function is chosen for all the criteria where the parameter s for each criterion is the value of 5. To show the calculation steps of how the values in table 8 are obtained, the following example can be given as follows: If the alternative *Concept A* is compared with the alternative *Concept B*, the related the values x_1, y_1 for P_1 (*Concept A, Concept B*) are calculated using the data in table 8 by Eq. (7) and Eq.(8) as given below;

$$x_1 = 8.00 - 5.00 = 3.00, \quad y_1 = 1 - e^{-(x_1^2)/(2*s^2)} = 1 - e^{-(3.00^2)/(2*5^2)} = 0.1647, \quad z = \sum_{i=1}^4 w_i * y_i = 0.10338$$

In addition; the z value is found after determining all the values of x_i, y_i for P_i ($i = 1, 2, 3, 4$) as the number of the concept alternatives. The results of the all the elements are given in table 9.

Table 8: Calculation steps of each element of aggregated preference index matrix

for P_1 (Concept A, Concept B)

Pairwise Comparison	w_i	x_i	y_i	z
P1 (Concept A, Concept B)	0.607	3.000	0.1647	0.10338
P2 (Concept A, Concept B)	0.263	-1.500	0.0000	
P3 (Concept A, Concept B)	0.077	1.500	0.0440	
P4 (Concept A, Concept B)	0.053	-2.500	0.0000	

Table 9. Aggregated preference index matrix

Alternatives	Concept A	Concept B	Concept C	Concept D
Concept A	0	0.10338	0.20215	0.31154
Concept B	0.01780	0	0.02776	0.13562
Concept C	0.13440	0.09767	0	0.16713
Concept D	0.00339	0.01268	0.00000	0

Later, by using the aggregated preference index matrix, the positive, negative and net outranking flows for each alternative are calculated by Eq. (9-10-11-12) and presented in table 10. As seen in table, the best alternative is *Concept A* and the ranking is found as; {*Concept A-Concept C-Concept B-Concept D*}.

Table 10: Outranking flow indices and rank through F-PROMETHEE II

Alternatives	Concept A	Concept B	Concept C	Concept D
ϕ^+	0.61707	0.18118	0.39919	0.01607
ϕ^-	0.15559	0.21373	0.22990	0.61429
ϕ	0.46148	-0.03255	0.16929	-0.59822
Ranking	1	3	2	4

4. Conclusions

The objective of the research was, to propose a F-AHP based F-PROMETHEE II approach to green concept selection problem. As the F-AHP is used to weight evaluation criteria, the F-PROMETHEE II are respectively used for ranking the concept alternatives, and determine the best concept alternative. Furthermore, the case study was inspired from the previous work of the author, which was realized in a hot runner systems manufacturer, used in injection molding systems in a Canada. In a new product development process, the back- and front- ends of development efforts mainly affects to determining the following criteria; *cost*, *risk*, *quality*, and *green* used in this paper. On the other hand, the F-MCDM methods have the following limitations; for instance; because the result (or ranking) of any method depends on the judgments of a DM. The possibility of bias of the DM to any particular alternative cannot be easily managed as especially in the F-AHP, because inconsistency value might lead to wrong results. Inclusion of environmental-related criteria into concept selection problem has been gaining increasing importance last decade.

Reference

- AYAG, Z. (2005a). An integrated approach to evaluating conceptual design alternatives in a new product development environment. *International Journal of Production Research*, 2005, Vol.43, No.4, s. 687-713.
- AYAG, Z. (2005b). A fuzzy AHP-based simulation approach to concept evaluation in a NPD environment. *IIE Transactions*. 2005, Vol. 37, s. 827-842.
- AYAG, Z., Ozdemir, R.G. (2007). An analytic hierarchy process-based approach to concept evaluation in a new product development environment", 2007. *Journal of Engineering Design*, Vol.18, s.209-226.
- AYAG, Z. (2014). An integrated approach to concept evaluation in a new product development. *Journal of Intelligent Manufacturing*, 2014, Vol.27, No.5, s. 991-1005.
- BRANS, J.P., VINCKE, Ph. and MARECHAL, B. (1986). How to select and how to rank projects: The PROMETHEE method, *European Journal of Operational Research*, 24, 228- 238.
- DUFFY, A.H.B., ANDREASEN, M. M., MACCALLUM, K. J. and REIJERS, L.N. (1993). Design coordination for concurrent engineering. 1993, *Journal of Engineering Design*, Vol.4, 251-261.
- FIGUEIRA, J., GRECO, S. and EHRGOTT, M. (2004). *Multiple Criteria Decision Analysis: State of the Art Surveys*, New York: Springer,
- LEE, A.R. (1999) Application of modified fuzzy AHP method to analyze bolting sequence of structural joints. *UMI Dissertation Services*, A Bell & Howell Company.
- SAATY, T. L. (1981). *The Analytical Hierarchy Process*. New York: McGraw Hill
- SAATY, T. L. (1989). Decision making, scaling, and number crunching. *Decision Science*. 1989, Vol. 20, s. 404-409.
- SAMANLIOGLU, F., AYAĞ, Z. (2016). A fuzzy ANP-based PROMETHEE II approach for evaluation of machine tool alternatives, *Journal of Intelligent and Fuzzy Systems*, Vol. 30, s. 2223-2235.
- ULRICH, K.T. and EPPINGER, S.D. (2000). *Product Design and Development*, Second Edition. New York: McGraw-Hill.
- WANG, Y. (2009). Centroid defuzzification and the maximizing set and minimizing set ranking based on α level sets, *Computers and Industrial Engineering*. Vol. 57, s. 228-236.
- ZADEH, L. A. (1965). Fuzzy sets. *Information and Control*, Vol. 8, s. 338-353.
- ZHANG, H.C., KUO, T.C., and LU, H. (1997). Environmentally conscious design and manufacturing: a state-of-the-art survey, *Journal of Manufacturing Systems*. Vol. 16, s. 352-371.