INDUSTRIAL COFFEE MACHINE SELECTION WITH THE FUZZY ANALYTIC HIERARCHY PROCESS

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Abstract- The consumption of products derived from coffee bean has been increasing rapidly. With this situation of the coffee industry, size and brand varieties of coffee market have been increasing too. Companies diversify the characteristics of the industrial coffee machines wide range to cater for demands of people in one machine. However, in most of countries, the coffee machine companies do not have sales network and cannot provide technical support. All of these factors may raise the prices of the industrial coffee machines and the price factor is not enough for the decision of the right coffee machine selection by itself like all other electronic devices. At the same time, intensive usage may cause extra costs for the companies with the shortening of machine life unless necessary and sufficient technical support is provided. Supplying sensitive and perishable parts of the machines on time is an important factor that affects the cost and the benefit of the company for purchasing. Some of other basic technical characteristics which determine the price of the coffee machine are number of the groups, water capacity, water pressure, cream quality, produced material, energy usage etc. All of these factors make decision making of the coffee machine selection harder. To this end, we will propose a Fuzzy Analytic Network Process (F–AHP) approach to select the most appropriate industrial coffee machine. Both initial costs and later costs are reduced as much as possible with selecting the best and the most appropriate equipment(s).

Index Terms- Analytic Hierarchy Process, Fuzzy Logic, Group Decision Making, Industrial Coffee Machine.

I. INTRODUCTION

Reducing the costs as least as possible is crucial for the persistence and profitability of the companies. Selecting the cheapest products reduce the costs at the beginning but it will be able to cause extra costs with breakdowns and technical requirements in the future periods. So, while selecting a technical equipment, price factor should not have to be considered solely. Therewithal, both technical details and after-sales support have to be considered. While considering all of these factors for an equipment, making the right decision manually is getting harder and wrong decisions may be taken unconsciously. Especially, buying an equipment with high initial prices may bring an end for a company if the equipment selection decision is improper.

The rest of the study is as follows. In the second section, a literature review for the Fuzzy AHP is given briefly. Fundamentals of fuzzy logic and triangular fuzzy numbers are explained in the third section. After the fuzzy logic, proposed Fuzzy AHP method is also presented in the third section. In the fourth section, the proposed F–AHP is applied to industrial coffee machine selection process and the fifth section is conclusions.

II. LITERATURE REVIEW

Because of the difficulties of selecting the best equipment, various multi criteria methods are chosen for equipment selection in the literature. Fuzzy multi criteria methods are common for the problems which have more than one decision maker. Evaluations are done with linguistic scales by the decision makers at the decision making process and analysis in the multi criteria methods are executed with these linguistic scales according to their fuzzy numbers.

F-AHP method is also applied for equipment selection problems in the companies commonly. Weck, Klocke, Schell and Rüenauver [1] applied F-AHP to evaluate production cycle alternatives in 1997. Three fuzzy result for the three alternatives are obtained at the end of the study and they are compared on a graphic.

Monitto, Pappalardo and Tolio [2] used a F-AHP to evaluate the best automated manufacturing system as a real life problem in 2002. Authors point to managing uncertainty and flexibilities with F-AHP in the study. Also in the study, they adverted that different assessment techniques may cause to different evaluation results. In 2004, Enea and Piazza [3] proposed a F-AHP approach with triangular fuzzy numbers for project evaluation. At the end of the analysis, the results of the study are also obtained with triangular fuzzy numbers and evaluated. Ayağ and Özdemir [4] introduced a F-AHP approach for machine tool selection problem in 2006. They evaluate three different alternatives with 19 criteria in the problem with using $\alpha-$cuts in the F-AHP. Same year, Noorul Haq and Kannan [5] applied F-AHP to a supply chain model for a vendor selection. Huang, Chu and Chiang [6] introduced a F-AHP which is applied to government-sponsored research and development project selection in Taiwan in 2008. In 2009, Cebeci [7] used a Fuzzy based AHP technique to evaluate Enterprise Resource Planning (ERP) system solutions for a textile company.

Hsu, Lee and Kreng [8] applied F-AHP to determine the importance degree of each criterion in lubricant regenerative technology selection problem in 2010.

The best supplier for a washing machine company is selected with using Fuzzy based AHP method by Kilincci and Onal [9] in 2011. They calculated both the weights of criteria and alternatives by using the Fuzzy AHP approach. In 2012, Shaw, Shankar, Yadav and Thakur [10] determine the weights of criteria with F-AHP in a developing low carbon supply chain problem. Then, they used the weights in fuzzy multi-objective linear programming method for the solution of the problem. In 2013, Jain, Singh and Mishra [11] determined the weights and prioritization for supplier selection criteria in the context of Indian manufacturing industry with a F-AHP approach. Junior, Osiro and Carpinetti [12] used F-AHP for a supplier selection decision in 2014. In the study, they compared the obtained results with Fuzzy AHP and Fuzzy TOPSIS (Technique for Order Performance by Similarity to Ideal Solution).

In the literature, fuzzy based multi criteria decision making methods are commonly used to evaluate the projects and equipment that have high costs and multiple subjective judgements. Deviations caused by subjective judgements and uncertainties can be reduced by using the fuzzy based methods.

III. FUZZY AHP

A. Fuzzy Logic

Fuzzy logic was developed from fuzzy set theory which was firstly introduced by Zadeh [13] in 1965. Fuzzy logic allows us to deal with uncertainty and subjective judgements of experts.

There are various fuzzy number types are used in literature and triangular fuzzy number is the most common one. Normally, a triangular fuzzy number is shown as $\tilde{A} = (a_1, a_2, a_3)$.

Let $\tilde{A} = (a_1, a_2, a_3)$ and $\tilde{B} = (b_1, b_2, b_3)$ be two different triangular fuzzy numbers and operations on triangular fuzzy numbers are done by using the following equations [14].

$$\tilde{A} + \tilde{B} = (a_1 + b_1, a_2 + b_2, a_3 + b_3) \quad (1)$$

$$\tilde{A} \cdot \tilde{B} = (a_1 \cdot b_1, a_2 \cdot b_2, a_3 \cdot b_3) \quad (2)$$

$$(-1) \cdot \tilde{A} = (-a_3, -a_2, -a_1) \quad (3)$$

$$\tilde{A}^{-1} = \left(\frac{1}{a_3}, \frac{1}{a_2}, \frac{1}{a_1}\right) \quad (4)$$

$$k \cdot \tilde{A} = (k \cdot a_1, k \cdot a_2, k \cdot a_3) \quad (5)$$

B. Fuzzy Analytic Hierarchy Process

Fuzzy Analytic Hierarchy Process (F-AHP) which is basically similar with AHP was firstly introduced by Saaty [15] in 1979. In F-AHP, fuzzy sets and fuzzy numbers are used instead of crisp sets and crisp numbers. Pairwise comparisons are applied with linguistic scales and fuzzy numbers in F-AHP method. Triangular fuzzy numbers will be used for pairwise comparisons and calculations in this study and the scale is given in Table I.

Table I
Linguistic pairwise comparison scale

Crisp Value	Linguistic Term	Fuzzy Number
1	Equally Important (EI)	(1,1,2)
3	Weakly Important (WI)	(2,3,4)
5	Important (I)	(4,5,6)
7	Strongly Important (SI)	(6,7,8)
9	Absolutely Important (AI)	(8,9,9)

The computational steps of proposed F-AHP approach is given in the following steps.

Step 1: Defining the problem: Firstly, the problem and the variables in the problem set are defined.

Step 2: Constructing the hierarchical structure: After defining the problem, alternatives and criteria, the hierarchical structure is constructed.

Step 3: Making the pairwise comparisons: Depend on the problem, decision makers or experts make the pairwise comparisons both among the alternatives and among the criteria.

Step 4: Aggregating the pairwise comparison matrices:

Pairwise comparison matrices which is done by decision makers or experts are aggregated by using the geometric mean formulation like AHP but with fuzzy numbers.

$$\tilde{a}_{ij} = \sqrt[D]{\prod \tilde{a}_{ij}^{d}} \quad (6)$$

D is the number of decision makers, $\tilde{a}_{ij}^{d}$ represents the i^{th} row j^{th} column evaluation of decision maker d and $\tilde{a}_{ij}$ represents the i^{th} row j^{th} column result of the aggregated pairwise comparison matrix in (1).

Step 5: Normalizations of the columns: Normalization for fuzzy numbers which was proposed by Wu and Lee [16] will be used in this step.

$$xl_{ij} = \left(l_{ij} - \min(l_{ij})\right) / \Delta_{\min}^{\max} \quad (7)$$

$$xm_{ij} = \left(m_{ij} - \min(l_{ij})\right) / \Delta_{\min}^{\max} \quad (8)$$

$$xr_{ij} = \left(r_{ij} - \min(l_{ij})\right) / \Delta_{\min}^{\max} \quad (9)$$

where $\tilde{a}_{ij} = (l_{ij}, m_{ij}, r_{ij})$ and $\Delta_{\min}^{\max} = \max(r_{ij}) - \min(l_{ij})$

Step 6: Calculating the fuzzy weights: Fuzzy weights are obtained by calculating the mean of the rows and calculation of the weights will be applied by using (10) for C criteria.

$$\frac{\sum_{i=1}^{C} \tilde{a}_{ij}}{C} \quad (10)$$

Step 7: Priority weights: After calculating the weights of the criteria and the weights vector of the alternatives for each criterion, priority weights for the alternatives are obtained by using (11).

$$\sum_{i=1}^{C} w_j \tilde{a}_{ij} \qquad (11)$$

Step 8: Defuzzification of the results: Results of fuzzy priority weight are defuzzified by using CFCS (Converting Fuzzy data into Crisp Scores) method [16] given below.

First step of the defuzzification is normalization given in (7)–(9).
Computing the left side (ls) and right side (rs) normalized values:

$$xls_i = xm_i / (1 + xm_i - xl_i) \qquad (12)$$
$$xrs_i = xr_i / (1 + xr_i - xm_i) \qquad (13)$$

Computing the total normalized crisp values:
$$x_i = [xls_i(1 - xls_i) + xrs_i xrs_i] / [1 - xls_i + xrs_i] \quad (14)$$

Computing the crisp values:
$$z_i = \min(l_i) + x_i \Delta_{\min}^{\max} \qquad (15)$$

IV. INDUSTRIAL COFFEE MACHINE SELECTION

The proposed F-AHP approach is applied to industrial coffee machine selection problem. A coffee house has five different brands' coffee machine alternatives and want to select one of them for the coffee house. All of the five coffee machines are selected from different brands' 3-group coffee machines. The names of the brands are hidden in the solution and "A i " represents the i^{th} alternative.
Evaluation criteria given in Table II are obtained by coffee machine experts and the owners of the coffee house who is the decision maker for this problem. After the calculations of the pairwise comparisons of the criteria obtained by the decision makers, fuzzy and crisp criteria weights given in Table III are obtained.

Table II
The evaluation criteria

Criteria	Name of the Criteria
C1	Price
C2	Electricity Usage
C3	Performance
C4	Steam Quality
C5	Water Pressure Quality
C6	Cream Quality
C7	Latte Production Time
C8	Single Espresso Production Time
C9	Design
C10	Opening Period
C11	Easy to Use
C12	Mug and Glass Diversity Used in the Machine

TABLE III
The Weights of The Evaluation Criteria

Criteria	Fuzzy Weights	Crisp Weights
C1	(0.240, 0.453, 0.794)	0.099
C2	(0.202, 0.376, 0.608)	0.084
C3	(0.307, 0.498, 0.851)	0.108
C4	(0.308, 0.523, 0.803)	0.109
C5	(0.166, 0.286, 0.539)	0.071
C6	(0.220, 0.414, 0.761)	0.094
C7	(0.046, 0.109, 0.211)	0.035
C8	(0.323, 0.490, 0.728)	0.104
C9	(0.182, 0.382, 0.665)	0.086
C10	(0.075, 0.143, 0.249)	0.041
C11	(0.559, 0.749, 1.000)	0.147
C12	(0.000, 0.044, 0.111)	0.022

After determining the criteria weights, alternatives are evaluated among themselves according to each criterion. All of 12 evaluations are in the matrix form whose dimensions are . Because of this situation and fuzzy numbers, they take too much places to show. So, we give only the normalized fuzzy weight results for each criterion in Table IV which is the fuzzy decision matrix of the industrial coffee machine selection problem.

TABLE IV
Fuzzy Decision Matrix of The Industrial Coffee Machine Selection

	C1	C2	C3	C4	C5	C6
A1	(0.032, 0.190, 0.544)	(0.112, 0.225, 0.393)	(0.093, 0.297, 0.635)	(0.220, 0.425, 0.845)	(0.247, 0.550, 1.000)	(0.075, 0.265, 0.602)
A2	(0.325, 0.558, 0.864)	(0.161, 0.287, 0.460)	(0.000, 0.097, 0.277)	(0.026, 0.192, 0.556)	(0.313, 0.551, 0.951)	(0.060, 0.240, 0.577)
A3	(0.000, 0.101, 0.255)	(0.000, 0.023, 0.063)	(0.357, 0.611, 0.943)	(0.221, 0.607, 1.000)	(0.091, 0.279, 0.541)	(0.000, 0.115, 0.282)
A4	(0.017, 0.124, 0.277)	(0.330, 0.505, 0.777)	(0.419, 0.654, 1.000)	(0.015, 0.161, 0.413)	(0.199, 0.482, 0.836)	(0.234, 0.420, 0.641)
A5	(0.436, 0.670, 1.000)	(0.576, 0.772, 1.000)	(0.045, 0.181, 0.394)	(0.000, 0.151, 0.413)	(0.000, 0.135, 0.452)	(0.191, 0.482, 1.000)

	C7	C8	C9	C10	C11	C12
A1	(0.272, 0.515, 1.000)	(0.063, 0.168, 0.347)	(0.275, 0.461, 0.665)	(0.000, 0.108, 0.258)	(0.000, 0.123, 0.314)	(0.288, 0.509, 0.958)
A2	(0.142, 0.397, 0.878)	(0.000, 0.040, 0.108)	(0.137, 0.261, 0.507)	(0.104, 0.261, 0.526)	(0.141, 0.306, 0.690)	(0.000, 0.107, 0.300)
A3	(0.000, 0.166, 0.352)	(0.096, 0.172, 0.320)	(0.000, 0.053, 0.155)	(0.099, 0.243, 0.453)	(0.038, 0.206, 0.470)	(0.025, 0.165, 0.423)
A4	(0.273, 0.559, 0.952)	(0.449, 0.704, 1.000)	(0.250, 0.508, 1.000)	(0.353, 0.612, 1.000)	(0.288, 0.564, 1.000)	(0.243, 0.556, 1.000)
A5	(0.169, 0.403, 0.909)	(0.185, 0.375, 0.647)	(0.161, 0.336, 0.548)	(0.071, 0.174, 0.347)	(0.140, 0.350, 0.625)	(0.240, 0.519, 0.884)

The next step is calculating the priority weights with using the values in Table IV and the weights of the evaluation criteria in (11). Obtained fuzzy priority weight results for the industrial coffee machine alternatives are given in Table V.

TABLE V
Fuzzy Priority Weights of the Alternatives

Alternative	Fuzzy Priority Weight
A1	(0.1172, 0.2890, 0.5812)
A2	(0.1181, 0.2710, 0.5516)
A3	(0.0893, 0.2468, 0.4622)
A4	(0.2523, 0.4731, 0.7984)
A5	(0.1824, 0.3743, 0.6685)

The last step of the calculations is defuzzification of the results according to Step 8 in Section III. Defuzzified and normalized priority weights for each alternative are given in Table VI. Results of the defuzzified priority weights show that the best alternative is the 4^{th} alternative with the result of the highest priority weight.

TABLE VI
Defuzzified Priority Weights of the Alternatives

Alternative	Crisp Priority Weights
A1	0.181
A2	0.172
A3	0.151
A4	0.273
A5	0.223

CONCLUSION

Group decision making process usually complicate to solve the problems. This study proposed a fuzzy analytic hierarchy process for industrial coffee machine selection problem is taken into consideration the evaluations of different experts and decision makers. The presented methodology can also be used for other equipment selection or multi criteria decision making problems. For further researches, the presented F-AHP methodology can also be integrated with other fuzzy multi criteria decision making methods to apply to various areas.

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