Fuzzy Cognitive Map Methodology For Evaluating Material Selection Criteria

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Abstract: - Material selection is a challenging procedure in engineering and design because of requiring to take into account many criteria from different dimensions. Being able to select proper materials and succeed to match the requirements in the production process is significant. The purpose of material selection process is to constitute optimum product that gives maximum performance and minimum cost. Material selection can be viewed as a complicated multi-criteria decision making (MCDM) problem, which requires the consideration of multiple conflicting criteria. This paper investigates the detailed evaluation of material selection factors by analyzing relationships and strength of them. Fuzzy cognitive map (FCM) methodology is employed to identify the most important factors in material selection. The application is illustrated through a case study of washing liquid material selection procedure.

Key-Words: -Decision support systems, fuzzy cognitive maps, material selection, multi-criteria decision making

I. INTRODUCTION

In manufacturing and design environment, material selection is considered as a key process in order to obtain cost reduction and better performance. Generally, the selection procedure is based on trial and error method performed by the experts, which may cause undesired selection. The complex relations between material alternatives and selection criteria make the selection procedure more difficult. Hence, a systematic and effective way for material selection is vital. Material selection is seen as a multi-criteria decision making (MCDM) problem that needs to consider multiple conflicting criteria.

In the literature, there are few studies that employed various MCDM methods for material selection. Ballestero [1] proposed a decision making methodology to select fabric for a textile company. Girubba and Vinodh [2] utilized VIKOR method as MCDM aid to identify the most appropriate material for instrument panel used in electric panel. Liu et al. [3] proposed an interval 2-tuple linguistic MCDM procedure to deal with the material selection in two different cases, for an automotive company and for a flywheel respectively. Liu et al. [4] integrated DEMATEL (decision-making trial and evaluation laboratory) based ANP (analytic network process) and VIKOR to resolve the bush material selection problem that consists of many interdependent attributes. Govindan et al. [5] constructed a model to select the most appropriate construction material by utilizing DEMATEL, ANP and TOPSIS. Zindani et al. [6] used TODIM (TOmada de DecisaoInterativaMulticriterio) for determining the most suitable materials. Recently, Ercan and Bilal [7] employed entropy based simple additive weighting and AHP to determine the most appropriate material used as a dental implant.

This paper investigates the detailed evaluation of material selection factors by analyzing relationships and strength of them. Fuzzy cognitive map (FCM) methodology is employed to identify the most important factors in material selection. FCM is viable modeling for researchers to reveal and analyze interrelationship among the identified concepts for tracking impacts of factors in the system [8]. FCM methodology is appropriate due to cause-and-effect relationships among factors, positive as well as negative relationships, and the lack of crisp data [9].

The rest of the study is organized as follows. Section II outlines the FCM methodology. Section III illustrates the case study and finally concluding remarks and future research directions are provided in Section IV.

II. FUZZY COGNITIVE MAP METHODOLOGY

Cognitive maps (CMs) were initiallyintroduced by Axelrod [10] as a tool in order to model decision aid frameworks in social and political sciences. CMs contain directed arcs that model causal relations and interrelationships among concepts. CMs may be applied in strategic planning, forecasting, and research and development.

In crisp (conventional) CM, binary relations (i.e., increase and decrease) are employed. On the other hand, forcing decision makers to form CM with crisp numbers may probably cause to insufficient information, like different numbers from different decision makers or different numbers from the same decision maker on different days. However, causal relations can be expressed by linguistic variables rather than numerical values by proposing fuzzy cognitive map (FCM) technique [11].

FCM is an expert based method of knowledge development in soft domains, provides combination of fuzzy logic and neural networks. FCM can be defined as an oriented graph, which shows the degree of causal relationship between different factors, where knowledge expressions, in the causal relationship, are expressed by either positive or negative sign and different weights [12].

FCM can be illustrated as a set of concepts and arrows that represent casual links among concepts. An arrow with positive sign from concept *A* to concept *B* indicates that increasing the value of concept *A* increases the value of concept *B* (positive relation). An arrow with negative sign from concept *A* to concept B indicates that increasing the value of concept *A* decreases the value of concept *B* (negative relation). Causal link is characterized by a weight that expresses the strength of relation [13].

The value of each concept is computed, taking into account the effect of the other concepts on the under-evaluation concept, by applying the following iterative formulation.

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j\neq i \\ j=1}}^{N} A_j^{(k)} w_{ji}\right) \quad (1)$$

where $A_i^{(k)}$ is the value of concept C_i at k^{th} iteration, w_{ji} is the weight of the connection from C_j to C_i and f is a threshold function.

The stepwise representation of the employed methodology, which is illustrated in Figure 1, is as [14]

Step 1. Create a committee of decision-makers and determine the evaluation criteria.

Step 2. Sign causal links among each pair of factors. The direction of causality links is represented as positive, negative, or null.

Step 3. Collect the data from experts by using nine linguistic terms such as negatively very strong (nvs), negatively strong (ns), negatively medium (nm), negatively weak (nw), zero (z), positively weak (pw), positively medium (pm), positively strong (ps), positively very strong (pvs) for relationships between the pair of concepts.

Step 4. Fuzzify the linguistic data.

Step 5. Aggregate three triangular fuzzy numbers for each relationship applying MAX aggregation, then defuzzify them by using centre of gravity method. The values are obtained, the weight matrix is achieved. This step is completed via MATLAB Fuzzy Toolbox.

Step 6. Start the iterative process with the initial vector $A^0 = [1,1,\ldots,1]$.

Step 7. Update the values of the initial vector via formulation (1). Use sigmoid function as a threshold function in order to restrict the values of in the interval [0,1].

Step 8. Repeat Steps 6-7 until reaching equilibrium, and calculate concept values, ie. importance degrees of factors.

III. CASE STUDY

The case study is conducted in a detergent manufacturer factory located in Turkey. The factory was founded in 2005 in Adana, south part of Turkey. Peros, Asperox, Sev, and Halk branded products are produced and brought to customer. It contributes positively to Turkey's economy by marketing its products to Middle East, Africa, Balkans and Turkic Republics. The factory has a capacity of producing 1500 tons detergent in a day and it is ranked among first 5 detergent manufacturers in Turkey.

An analysis is conducted with research and development (R&D) department and five criteria that are used in material evaluation process are determined as "pH (C_1)", "viscosity (C_2)", "anionic active material (C_3)", "nonionic active material (C_4)", "total active material (C_5)". Evaluation criteria with the labels are listed in Table 1.

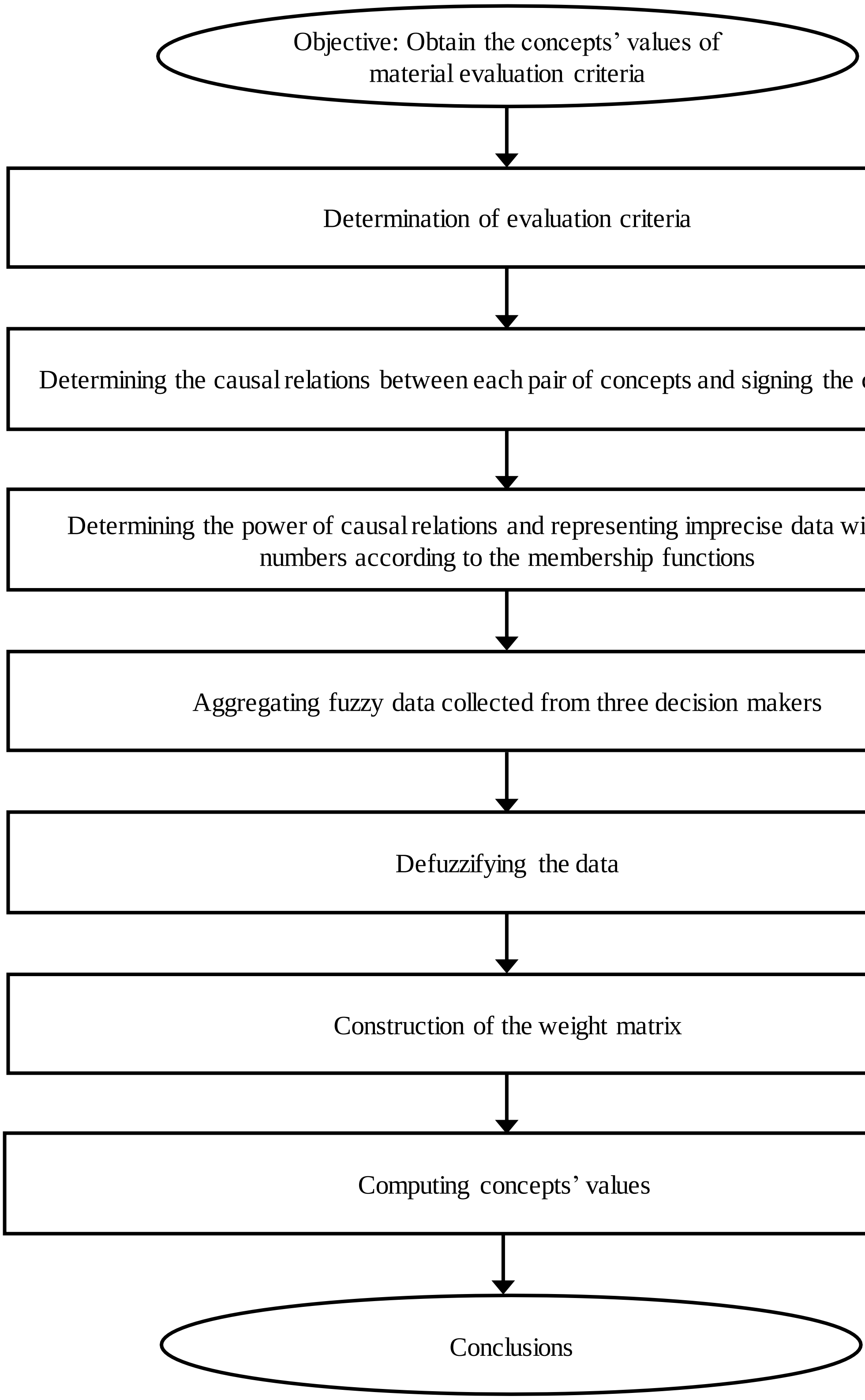

Figure 1. Thestepwiseillustration of theemployedmethodology

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Table 1. Material evaluation criteria

Label	**Concept**
C_1	pH
C_2	viscosity
C_3	anionic active material
C_4	nonionic active material
C_5	total active material

Three decision-makers indicate the direction of causal relationships in three categories: positive, negative, null. Experts decide the degree of causal links by using linguistic variables; subsequently linguistic variables are transformed into fuzzy numbers. In this study, nine linguistic terms are used as negatively very strong (nvs), negatively strong (ns), negatively medium (nm), negatively weak (nw), zero (z), positively weak (pw), positively medium (pm), positively strong (ps), positively very strong (pvs). The corresponding triangular fuzzy numbers for these linguistic variables are reported in Table 2.

Table 2. Scale of Fuzzy Numbers [9]

Linguistic Term	**Fuzzy Number**
nvs	(-1,-1,-0.75)
ns	(-1,-0.75,-0.5)
nm	(-0.75,-0.5,-0.25)
nw	(-0.5,-0.25,0)
z	(-0.25,0,0.25)
pw	(0,0.25,0.5)
pm	(0.25,0.5,0.75)
ps	(0.5,0.75,1)
pvs	(0.75,1,1)

The matrices of power of causalities are given in Tables 3,4, and 5.

Table 3. Matrix of power of causalities according to Expert 1

	C_1	C_2	C_3	C_4	C_5
C_1	x	z	z	z	z
C_2	z	x	z	z	z
C_3	pm	pvs	x	pw	pm
C_4	pm	ps	pw	x	ps
C_5	p	pm	z	z	x

Table 4. Matrix of power of causalities according to Expert 2

	C_1	C_2	C_3	C_4	C_5
C_1	x	z	z	z	z
C_2	z	x	z	z	z
C_3	pm	pm	x	pm	pm
C_4	ps	pm	pw	x	pm
C_5	ps	pvs	z	z	x

Table 5. Matrix of power of causalities according to Expert 3

	C_1	C_2	C_3	C_4	C_5
C_1	x	z	z	z	z
C_2	z	x	z	z	z
C_3	ps	ps	x	pw	ps
C_4	pm	pm	ps	x	ps
C_5	ps	ps	z	z	x

The linguistic data that were collected from experts were converted into triangular fuzzy numbers according to the membership functions mentioned in Table 2. These triangular fuzzy numbers are aggregated via MAX aggregation, and then defuzzified by employing COG method, and the weight matrix is obtained as in Table 6. MATLAB fuzzy tool box is used for these operations. With regard to the weight matrix, FCM is constructed as in Figure 2.

Table 6. Weight matrix

	C_1	C_2	C_3	C_4	C_5
C_1	0	0	0	0	0
C_2	0	0	0	0	0
C_3	0.63	0.67	0	0.38	0.63
C_4	0.63	0.63	0.50	0	0.63
C_5	0.63	0.67	0	0	0

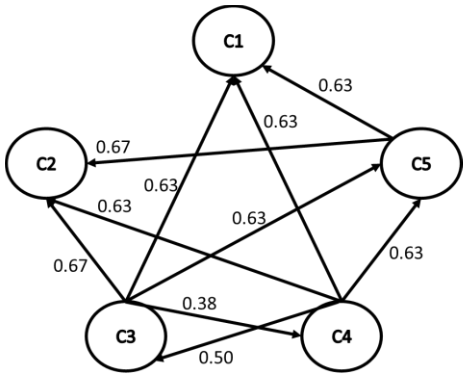

Figure 2 .FCM

In order to obtain concepts' values, the iterative formulation of FCM is run via FCMapper software. Concept values are given in Table 7.

Table 7. The concepts' values of material evaluation criteria

Label	Concept	Concept's value
C_1	pH	0.9165
C_2	viscosity	0.9217
C_3	anionic active material	0.7544
C_4	nonionic active material	0.7354
C_5	total active material	0.8577

IV. CONCLUSION

In order to obtain the concepts' values of material evaluation criteria, factors are listed through expert opinions and the literature review. Experts decided whether there is causality or not. If there is causality between each pair of concepts, then they determine the sign of the relationship. After that the weight of outlined causal links was decided according to specified linguistic variables. These linguistic variables are converted into fuzzy numbers according to the associated membership function and they were aggregated by using MATLAB Fuzzy Toolbox. Finally, aggregated fuzzy numbers were defuzzified by using MAX and center of gravity methods to compose weight matrix. The result of FCMapper reveals that "viscosity" is the most important material evaluation criteria, which is followed by "pH" and "total active material".

Future research directions will focus on selecting the most appropriate material by employing a fuzzy multi-criteria decision making technique.

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