A Fuzzy MCDM Approach to Determine Critical Evaluation Criteria in Washing Liquid Material Selection Procedure

Mehtap Dursun and Özlem Arslan

Abstract—**Selection of an appropriate material has become a key issue in the design and development of new products. Material selection can be viewed as a complicated multi-criteria decision making (MCDM) problem which requires the consideration of multiple conflicting criteria. The aim of this paper is to present a fuzzy multi criteria decision making (MCDM) approach based on 2-tuple fuzzy linguistic model, linguistic hierarchies and quality function deployment (QFD) to determine the importance of selection criteria in material selection procedure. The proposed methodology illustrated through a case study of washing liquid material selection procedure.**

Index Terms— **Linguistic hierarchies, material selection, new product development, quality function deployment, 2-tuple fuzzy linguistic representation**

I. INTRODUCTION

NEW product development process (NPD) is considered as the key factor of competition among different markets [1]. It is based on converting an idea into visible, touchable entity. The purpose is meeting the desires of higher quality and performance at lower cost [2]. To make proper decisions in NPD is vital because the failure rate doesn't underestimate and cost of failure is very high.

Material selection is a challenging procedure in NPD. It is seen as a multi-criteria decision making (MCDM) problem in engineering because of requiring to consider multiple criteria from different dimensions. Being able to select proper materials and succeed to match the requirements in the production process is significant. Improper material selection may affect the performance of products negatively, thus productivity, success and prestige of the firm are also effected poorly [3]. The purpose of material selection process is to constitute effective product that gives maximum performance at minimum cost.

In the literature, there are some articles related to material selection. Chatterjee and Chakraborty [4] applied four preference ranking based MCDM methods to solve a material selection problem. Girubba and Vinodh [5] utilized VIKOR method as MCDM tool to determine the most appropriate material for instrument panel used in electric panel. Rahman et al. [6] proposed a knowledge based decision support system to make ideal materials selections for roof design. The procedure utilized TOPSIS method to facilitate selection process. Liu et al. [3] proposed an approach that employs MCDM method with interval 2-tuple linguistic information to solve the material selection problem in two different cases, for an automative company and for a flywheel respectively. Anojkumar et al. [7] introduced 4 different MCDM methods, fuzzy analytic hierarchy process (FAHP)-technique for Order of Preference by Similarity to Ideal Solution (TOPSIS), FAHP-VIKOR, FAHP-ELECTRE and FAHP-PROMTHEE to select material for the pipes in sugar industry by taking into account different alternatives and evaluation criteria. Liu et al. [8] integrated decision-making trial and evaluation laboratory (DEMATEL) based analytic network process (ANP) and VIKOR to resolve the bush material selection problem that consists of many interdependent criteria. Liao [9] presented interval type 2 fuzzy multi-attribute decision making for material selection. The method is illustrated in an engineering application of material selection in a jet fuel system. Govindan et al. [10] constructed a model to select the most appropriate construction material by utilizing DEMATEL, ANP and TOPSIS.

This paper focuses on determining the importance of selection criteria, which are considered to evaluate washing liquid that meets the needs of both customers and firms. A fuzzy multi-criteria group decision making approach based on quality function deployment (QFD), 2-tuple fuzzy linguistic representation and linguistic hierarchies is presented. QFD is used to incorporate customer requirements into the evaluation process. 2-tuple fuzzy linguistic representation and linguistic hierarchies are employed to unify multigranular linguistic information provided by decision makers.

The rest of this paper is organized as follows. In Section 2, QFD was introduced briefly. In section 3, and section 4, 2-tuple fuzzy linguistic representation and linguistic hierarchies are presented, respectively. The proposed algorithm is explained in section 5 and a case study is illustrated in section 6. Finally, concluding statements are given in the last section.

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II. QUALITY FUNCTION DEPLOYMENT

Quality function deployment (QFD) is accepted as an important product development method which aims to convert customer requirements into activities to develop product and services [11]. OFD needs to identify customer requirements and desires for being able to constitute product and services according to these necessities and requirements. In this way, QFD tries to maximize customer satisfaction level. On the other hand, designating resources by considering customer needs leads to reduction in cycle time and falling in production cost [12].

QFD has 4 different matrices. Each matrix has its own task for phases in product development process. These matrices can be listed as product planning, part deployment, process planning and production/operation planning matrices, respectively. Product planning matrix provides translating customer needs (CNs) into measurable technical attributes (TAs). Part deployment matrix converts important TAs to product/part characteristics. Process planning matrix translates important product/part characteristics into manufacturing operations. And production/operation planning matrix provides to convert important manufacturing operations to day to day operations and controls [13].

The first of the four matrices, also called the house of quality (HOQ), is the most frequently employed matrix in QFD. HOQ consists of seven cells, which has different task . Each cell clarifies a relationship between CNs and TAs and among the TAs.

The structure of HOQ matrix is presented in Figure 1.

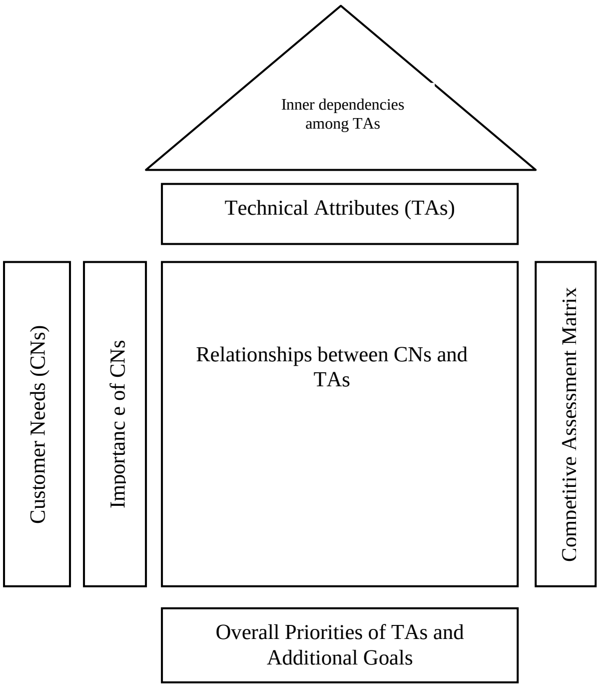


Fig. 1. The house of quality

III. 2-TUPLE FUZZY LINGUISTIC REPRESENTATION MODEL

Decision making is an activity that is related making choice among alternatives in order to reach intended aims. Since decision making problems in real world includes uncertainties and imprecision, using computational methods can not be sufficient alone in some cases. Thus, using linguistic information makes easier decision making process. Moreover, qualitative evaluation is easier and comfortable for humans in terms of transmitting their opinions.

2-tuple linguistic model is the most convenient way in linguistic decision making. It was presented by Herrera and Martinez [14]. The main advantage of this model is the prevention of loss of information. The basic representation of 2-tuple fuzzy linguistic model is (s_i, α) where s_i represents the linguistic label of the predefined linguistic term set S_T, and α is a numerical value.

Comparison of linguistic 2-tuples can be represented as follows:

Let (s_x, α_1) and (s_y, α_2) be two 2-tuples.

- If $x < y$ then $(s_x, \alpha_1) < (s_y, \alpha_2)$
- If $x = y$ then
    - If $\alpha_1 = \alpha_2$ then (s_x, α_1) and (s_y, α_2) represent same information.
    - If $\alpha_1 < \alpha_2$ then $(s_x, \alpha_1) < (s_y, \alpha_2)$
    - If $\alpha_1 > \alpha_2$ then $(s_x, \alpha_1) > (s_y, \alpha_2)$

Important definitions are given as follows:

***Definition* 1 [15].** Let $L = (\gamma_0 , \gamma_{1,\dots,}\ \gamma_g)$ be a fuzzy set defined in S_T. A transformation function χ that transforms L into numerical value in the interval of granularity of S_T , [0,g] is defined as

$$\chi : F(S_T) \rightarrow [0, g],$$

$$\chi(F(S_T)) = \chi(\{(s_j, \gamma_j), j = 0,1,\dots, g\}) = \frac{\sum_{j=0}^{g} j\gamma_j}{\sum_{j=0}^{g} \gamma_j} = \beta \qquad (1)$$

where $F(S_T)$ is the fuzzy sets defined in S_T.

***Definition* 2 [14]:** Let $S = \{s_0, s_1, \dots, s_g\}$ be a linguistic term set and $\beta \in [0, g]$ a value supporting the result of a symbolic aggregation operation, then the 2-tuple that expresses the equivalent information to β is obtained with the following function:

$$\Delta : [0, g] \rightarrow S \times [-0.5, 0.5),$$
$$\Delta(\beta) = \begin{cases} s_i, & i = \text{round}(\beta) \\ \alpha = \beta - i, & \alpha \in [-0.5, 0.5) \end{cases} \qquad (2)$$

where 'round' is the usual round operation, s_i has the closest index label to 'β', and 'α' is the value of the symbolic translation.

***Proposition* 1 [14]:** Let $S = \{s_0, s_1, \dots, s_g\}$ be a linguistic term set and (s_i, α) be a 2-tuple. There is a Δ^{-1} function such that from a 2-tuple it returns its equivalent numerical value $\beta \in [0, g] \subset \Re$. This function is defined as

$$\Delta^{-1} : S \times [-0.5, 0.5) \to [0, G], \quad \Delta^{-1}(s_g, \alpha) = g + \alpha = \beta \tag{3}$$

Definition 3 [16, 17]: Let $x = \{(s_1, \alpha_1), \ldots, (s_n, \alpha_n)\}$ be a set of linguistic 2-tuples and $W = \{(w_1, \alpha_1^w), \ldots, (w_n, \alpha_n^w)\}$ be their linguistic 2-tuple associated weights. The 2-tuple linguistic weighted average $\bar{x}_l^w$ is calculated with the following function:

$$\bar{x}_l^w\left(\left[(s_1, \alpha_1), (w_1, \alpha_1^w)\right] \ldots \left[(s_n, \alpha_n), (w_n, \alpha_n^w)\right]\right) = \Delta\left(\frac{\sum_{i=1}^{n} \beta_i . \beta_{w_i}}{\sum_{i=1}^{n} \beta_{w_i}}\right) \tag{4}$$

with $\beta_i = \Delta^{-1}(s_i, \alpha_i)$ and $\beta_{w_i} = \Delta^{-1}(w_i, \alpha_i^w)$.

IV. LINGUISTIC HIERARCHIES

A linguistic hierarchy comprises set of levels. Each level is a linguistic term set that has different granularity. The levels in this hierarchy is symbolized as $l(t,n(t))$, where t denotes the level of hierarchy and $n(t)$ denotes granularity of the linguistic term set of the level t [18].

The linguistic hierarchy, LH can be considered as the union of all levels t as $LH = \bigcup_t l(t, n(t))$. The linguistic term set of level t+1 is obtained as [19]

$$L(t, n(t)) \to L(t+1, 2.n(t) - 1) \tag{5}$$

Linguistic hierarchies are utilized for preventing information loss in the unification phase. The transformation function is formulized as

$$TF_{t'}^{t} : l(t, n(t)) \to l(t', n(t')), \quad TF_{t'}^{t}\left(s_i^{n(t)}, \alpha^{n(t)}\right) = \Delta\left(\frac{\Delta^{-1}\left(s_i^{n(t)}, \alpha^{n(t)}\right)\left(n(t') - 1\right)}{n(t) - 1}\right) \tag{6}$$

The transformation function is bijective that provide transformations by preventing loss of information [18].

V. PROPOSED DECISION MAKING ALGORITHM

This section represents the fuzzy group decision making methodology, which is based on QFD. The proposed methodology employed linguistic hierarchies and 2-tuple fuzzy linguistic representation model to unify and aggregate multigranular linguistic information provided by decision-makers. Moreover, it uses QFD to determine the weights of the evaluation criteria. The detailed stepwise representation of the proposed fuzzy MCDM algorithm is given below.

Step 1. Construct a decision-makers' committee of Z (z=1,2,…,Z) experts, and identify the CNs (i=1,2,…,m) and required selection criteria (j=1,2,…,n).
Step 2. Construct the decision matrices for each decision-maker that denote the weights of each CNs, $\tilde{w}_{iz}$, relationships among CNs and TAs, $\tilde{x}_{ijz}$, and inner dependencies among TAs, $\tilde{y}_{kjz}$.
Step 3. Unify the multigranular linguistic information given by the decision-makers into a linguistic term set employing Eq. (6).
Step 4. Aggregate the weights of each CNs, relationships among CNs and TAs, and inner dependencies among TAs employing arithmetic mean operator.
Step 5. Compute the β values of the aggregated ratings.
Step 6. Calculate the original relationship measure between the jth TA and the ith CN, $\tilde{x}_{ij}^{*}$, employing Eq. (4).
Step 7. Compute the 2-tuple linguistic weighted average for each TA.
Step 8. Rank the TAs according to the principles of comparison of linguistic 2-tuples given in Section III.

VI. CASE STUDY

The application of the proposed methodology is illustrated through a case study conducted in a detergent manufacturer factory located in south part in Turkey. The factory has a capacity of producing 1500 tons detergent in a day and it is ranked among first 5 detergent manufacturers in Turkey.

First, an analysis is conducted with quality control department and the features of detergents, expectations of customers, factors that effects on production process are stated. Then a survey is constructed with the contribution of quality control department.

Five CNs through expectations of customers are decided. These can be listed as "easy resolution in water (CN_1)", "eco friendly (CN_2)", "anti allergen (CN_3), "cost effective (CN_4), "hygienic (CN_5)".

Five TAs that are considered as evaluation criteria can be listed as "pH (TA_1)", "viscosity (TA_2)", "anionic active material (TA_3)", "nonionic active material (TA_4)", "total active material (TA_5)".

Four decision-makers (DM_1, DM_2, DM_3, DM_4) stated their opinions on the prepared survey. The linguistic hierarchy, $LH = \bigcup_t l(1,3)$, shown in Figure 2 [20], is considered as multigranular linguistic context, since the granularity of its linguistic term sets are very common in decision-making problems.

DM_1 used $l(1,3)$, DM_2 and DM_3 used $l(2,5)$, and DM_4 preferred to use $l(3,9)$, and DM_3 preferred to use $l(3,9)$ for rating the prepared survey. First, the decision-makers provided their opinions on the effects of each TA on each CN. Then, they stated the importance of each CNs and finally the dependencies among TAs are given. The linguistic term set l(2,5) is chosen as linguistic terms set to unify the multigranular linguistic information provided by the decision-makers. The unified assessments of decision-makers are aggregated employing arithmetic mean operator and the results are given in Figure 3.

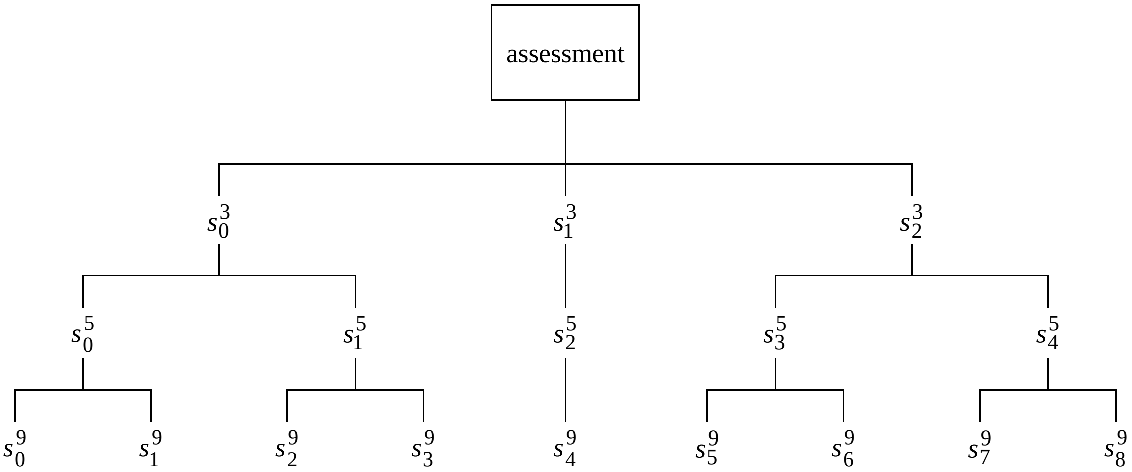


Fig. 2. The linguistic hierarchy $LH = \bigcup_t l(1,3)$ [20]

The original relationship measure between CNs and TAs is calculated as in Table I.

TABLE I
ORIGINAL RELATIONSHIP BETWEEN CNS AND TAS

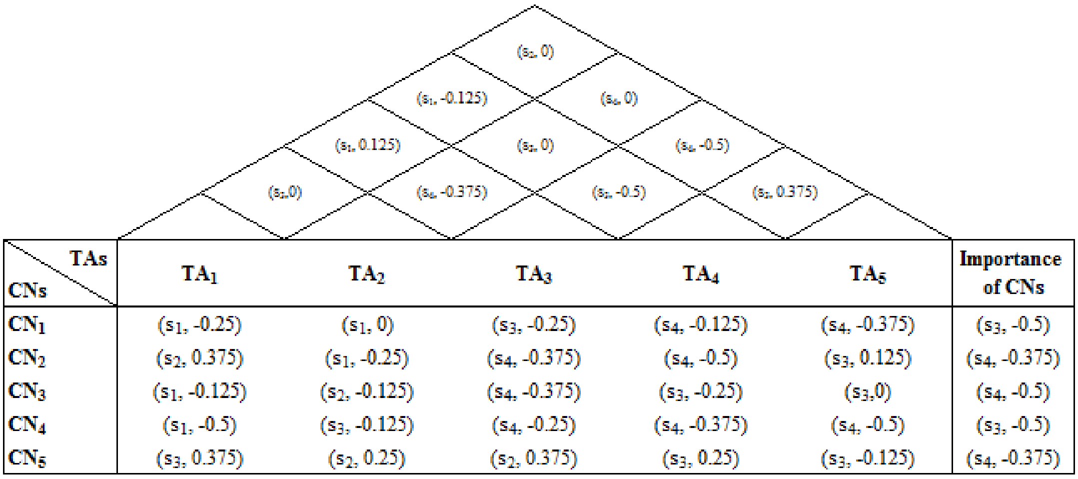
	TA_1	TA_2	TA_3	TA_4	TA_5
CN_1	(s_2, -0.21)	(s_2, 0.40)	(s_3, -0.43)	(s_3, -0.22)	(s_3, -0.47)
CN_2	(s_2, 0.29)	(s_3, -0.37)	(s_3, -0.32)	(s_3, -0.24)	(s_3, -0.35)
CN_3	(s_2, -0.04)	(s_2, 0.47)	(s_3, -0.31)	(s_3, -0.34)	(s_3, -0.44)
CN_4	(s_2, 0.27)	(s_3, -0.08)	(s_3, 0.21)	(s_3, 0.26)	(s_3, 0.07)
CN_5	(s_3, -0.13)	(s_3, -0.22)	(s_3, -0.31)	(s_3, -0.21)	(s_3, -0.24)

2-tuple linguistic weighted average for each TA is computed and the TAs are ranked according to the principles of comparison of linguistic 2-tuples. The results are given in Table II.

TABLE II
IMPORTANCE OF TAS

	TA_1	TA_2	TA_3	TA_4	TA_5
Importance	(s_2, 0.27)	(s_3, -0.36)	(s_3, -0.25)	(s_2, 0.24)	(s_3, -0.30)
Rank	IV	III	I	V	II

According to the results of the analysis, "anionic active material (TA_3)" is determined as the most important evaluation criteria for washing liquid material selection procedure, which is followed by "total active material (TA_5)" and "viscosity (TA_2)", "pH (TA_1)", and "nonionic active material (TA_4)", respectively.



CNs \ TAs	TA_1	TA_2	TA_3	TA_4	TA_5	Importance of CNs
CN_1	(s_1, -0.25)	(s_1, 0)	(s_3, -0.25)	(s_4, -0.125)	(s_4, -0.375)	(s_3, -0.5)
CN_2	(s_2, 0.375)	(s_1, -0.25)	(s_4, -0.375)	(s_4, -0.5)	(s_3, 0.125)	(s_4, -0.375)
CN_3	(s_1, -0.125)	(s_2, -0.125)	(s_4, -0.375)	(s_3, -0.25)	(s_3,0)	(s_4, -0.5)
CN_4	(s_1, -0.5)	(s_3, -0.125)	(s_4, -0.25)	(s_4, -0.375)	(s_4, -0.5)	(s_3, -0.5)
CN_5	(s_3, 0.375)	(s_2, 0.25)	(s_2, 0.375)	(s_3, 0.25)	(s_3, -0.125)	(s_4, -0.375)

Fig. 3. Unified assessments of decision-makers

VII. CONCLUSION

Material selection problem can be grouped as an important decision making problems because of the consideration of conflicting criteria and alternatives that have to be considered simultaneously.

In this paper, a fuzzy multi-criteria decision making algorithm, which combine 2-tuple fuzzy linguistic modeling, linguistic hierarchies and quality function deployment is proposed to determine the importance of selection criteria in material selection procedure.

Future research might focus on the improvement of the proposed algorithm to constate the most appropriate material alternative for washing liquid.

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