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WASHING LIQUID MATERIAL SELECTION USING FUZZY MULTI-CRITERIA DECISION MAKING APPROACH

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WASHING LIQUID MATERIAL SELECTION USING FUZZY MULTI-CRITERIA DECISION-MAKING APPROACH

(BULANIK ÇOK KRİTERLİ KARAR VERME YAKLAŞIMI KULLANARAK BULAŞIK DETERJANI MALZEME SEÇİMİ)

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ABSTRACT

Multi-criteria decision-making (MCDM) that is encountered in daily life commonly, is an important issue. Thus it has a high importance in literature. Material selection is the another important concept. The idea behind material selection is based on MCDM. The problem that is aimed to be solved in this thesis is basically a material selection problem. In a detergent manufacturing factory, 6 different kinds of washing liquid formulation alternatives are presented. The aim is selecting the most appropriate formulation that meets the needs best. Firstly an analysis is conducted with the quality control department of factory and customer needs (CNs) and technical attributes (TAs) are identified. While CNs are determined as "easy resolution in water (CN_1)", "eco-friendly (CN_2)", "anti-allergen (CN_3), "cost effective (CN_4), "hygienic (CN_5)", TAs are determined 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 state their opinions on prepared survey. CN & TA relationship matrix, TA & TA relation matrix and Importance of CNs matrix are formed according to results of this survey. The importance of TAs are determined after the applying Quality Function Deployment (QFD), 2-tuple fuzzy linguistic representation and linguistic hierarchies methods. "Anionic Active Material (TA_3)" is decided as the most important evaluation criteria and weights are assigned to each TA. Secondly, linguistic ratings for each formulation alternatives according to TAs are taken from 3 decision makers and fuzzy technic for order preference by similarity to ideal solution (TOPSIS) method is applied and Formulation 4 is determined the best washing liquid alternative among 6 alternatives.

ÖZET

Malzeme seçim problemi, çok kriterli karar verme içerisinde değerlendirilebilecek bir problemdir. Belirlenen kriterler ve şartlar altında, beklentileri ve gereksinimleri en iyi şekilde karşılayabilen ve en çok işe yarar alternatifi seçebilmek, malzeme seçiminin temel ilkesidir. Bu tezde, deterjan üreten bir fabrika ele alınmıştır. Temel amaç, içerikleri farklı olan 6 bulaşık deterjanı arasından en olumlu seçimi yapmaktadır. Bulaşık deterjanı üretilirken, müşteri gereksinimleri 'suda kolay çözünebilme', 'çevre dostu olma', 'cilde zarar vermeme', 'uygun fiyatlı olma' ve 'iyi temizleme' olarak belirlenir. Bulaşık deterjanının teknik özellikleri ise 'ph', 'viskozite', 'anyonik aktif madde', 'noniyonik aktif madde' ve 'toplam aktif madde' olarak belirlenir. 4 farklı karar verici tarafından bu özelliklerin oylanması istenir ve bu oylamalar dikkate alınarak her bir teknik özellik için bulanık karar verme yöntemleri uygulanır, ağırlıklar elde edilir. 'Anyonik aktif madde' en yüksek ağırlığı olan teknik özellik olarak bulunur. Bundan sonraki adımda ise karar verici sayısı 3'e düşürülerek her bir karar vericinin, her bir alternatif bulaşık deterjanı için, teknik özellikler dikkate alınarak oylama yapması istenir. Uygulanan bulanık TOPSIS yöntemiyle, belirlenen kriterler, teknik özelliklere verilen ağırlıklar doğrultusunda, ihtiyaçlara en uygun bulaşık deterjanı alternatifinin, 4. formülasyon olduğu bulunur.

1. INTRODUCTION

New product development (NPD) process is considered as the key factor of competition among different markets (Brown and Eisenhardt, 1995). This process based on converting an idea into visible, touchable entity. To obtain a new product can be provided by taking most appropriate decisions in each level of developing process, therefore every step taken by decision makers are very important. In addition, effective management of product development process is also critical (Büyüközkan and Feyzioğlu, 2004).

The development process starts with producing new ideas and converting these ideas into a proposal. Unapplicable ideas are eliminated while applicables are elaborated. After that, a survey should be conducted among target consumers in order to determine the necessities of consumers and compare these necessities according to company's policy. The purpose is meeting the desires of higher quality and performance at lower cost (Maffin and Braiden, 2001). Cost-benefit analysis is done by taking into account designated criteria. If all these evaluations are positive, the new product development process starts.

Making proper decisions in NPD process is vital because the failure rate does not underestimate and cost of failure is very high. Moreover, researchers indicate that it is difficult to terminate an NPD project if it is begun (Cooper, 2003). Developing a successful new product that meets the necessities requires proper material selection. These procedures based on decision making. Decision making is an activity that is related making a choice among alternatives in order to reach intended aims. Decision making exists in essence of life. All humans from different stratum of society have to make a choice in all stage of their life. The purpose of decision making is finding a proper choice that meets the needs best.

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. In case of selecting materials improperly, the process will fail and intended success won't be achieved. Due to extensive variety of materials, the selection process becomes more difficult. The purpose of material selection process is to constitute optimum product that gives maximum performance and minimum cost.

It is very common to encounter real decision making problems in daily life and have to be faced conflicting aims. Sustaining a complex life in today makes harder understanding the world, interpreting the life correctly by thinking just one direction and abiding by one criterion. Life always offers possibilities.

Multi-criteria decision making (MCDM) includes methods that satisfy more than one criterion from different perspectives and aims to reach the probable solution. If a problem is considered as an MCDM problem, it is possible if and only if the problem has to include more than one conflicting criteria and at least two possible solutions. Material selection is accepted as a kind of MCDM problem. While restrictions of companies have to be considered, it is hard to find ideal material that meets the desires of customer. Many factors in terms of both customers and company have to be taken into account. Thus this process becomes very complicated. Choosing applicable material is a critical issue for the future of companies.

The objective of this thesis is determining the importance of selection criteria, which are considered to evaluate washing liquid that meets the needs of both customers and firms. Also, the thesis aims to select the most appropriate alternative among different formulations. 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 linguistc representation and linguistic hierarchies are employed to unify multigranular linguistic information provided by decision makers. Finally fuzzy TOPSIS method is employed to rank the alternatives.

The rest of the thesis is organized as follows. In Section 2, a general literature review on NPD is introduced. Section 3 explains the basics of QFD. Fuzzy set theory is presented in Section 4. Section 5 and Section 6 represent 2-tuple linguistic representation model and linguistic hierarchies, respectively. Fuzzy TOPSIS method is given Section 7. The proposed algorithm is explained in Section 8 and a case study is illustrated in Section 9. Finally, concluding statements are given in the last section.

2. LITERATURE REVIEW

In the literature, there are many articles that evaluate new product development studies. It is possible to classify these studies according to the methods used.

The studies that utilized statistical methods can be classified in the first group. Path model approach is the method used by Swink and Song (2007) to examine the positive and negative sides of marketing manufacturing integration in each level of NPD. Afonso et al. (2008) applied multiple linear regression model to explore the relationship target costing (TC) and time-to-market (TtM) on NPD success. Liao et al. (2008) introduced Apriori algorithm for presenting a product map to find a possible solution for NPD and marketing problems. Tang et al. (2011) proposed a novel method to generate belief rule base (BRB) for belief rule base interference methodology (RIMER) to allow risk analysis in NPD. Structural equation model (SEM) was used with neuro-fuzzy inference system (ANFIS) by Ho and Tsai (2011) for comparing with each other in the forecasting of value innovation models. Covariance-based path analysis with maximum likelihood estimation method was used by Carbonel and Escudero (2013) for examining the effects of formal and informal management controls on the issue of job satisfaction and decision making in new product development team.

Chen et al. (2014) applied regression analysis for exploring the relationship between human capital, organizational capital and customer capital and if they have an impact on NPD performance or not. Homburg and Kuehnl (2014) utilized hierarchical analysis in regression models to find which level of customer integration in NPD will be most effective. Analysis of Variance (ANOVA) method was employed by Liang et al. (2014) to investigate the effects of culture in decision making in the context of NPD by considering two countries, US and China. Marmier et al. (2014) constructed a decision tree and resolute this decision tree by backward method for providing an easiness to decision makers with the way of forming relations between project management, risk management and design management by managing risk factor professionally. Oehmen et al. (2014) made an investigation related to impacts of risk management activities on NPD process by using Goodman and Kruksal's Gamma statistical methods. ANOVA method was proposed by Rossi et al. (2014) to find NPD best practices in the context of a technique, a method or an activity that is able to deliver the products ideally. Confirmatory factor analysis was employed by Zhao et al. (2014) for exploring the correlation of NPD tasks and black-box supplier integration.

Lately, Benedetto (2015) employed multivariate analysis of variance (MANOVA) to provide cross-functional integration in the NPD process by focusing the affects the integration of environmental specialist into new product development teams. Confirmatory factor analysis was presented by Chen et al. (2015) for exploring the results of NPD outcomes based on team autonomy under different levels of technological turbulence. González et al. (2015) utilized moderated hierarchical regression analysis to explore the effects of using formal liaision devices by firms on the relationship between knowledge acquisition from suppliers and competitors. Gopalakrishnan et al. (2015) used analysis of covariance (ANCOVA) method to predict a relationship between the type of NPD process and cost reduction performance. Path analysis and multiple regression models are the methods that were utilized by Lechler and Thomas (2015) for defining the NPD termination decisions at the organizational level of some German firms by considering accuracy and timing. Mazzola et al. (2015) introduced eigenvector centrality to explore the influence of structural embeddedness positions, centrality and structural holes on the NPD period. Mu (2015) applied confrimatory factor analysis with maximum likelihood estimation method for exploring whether marketing capability from an outside-in perspective has a positive impact on NPD performance. Logistic regression procedure was combined with casual steps approach by Baron and Kenny and the PROCESS analysis by Hayes methods by Xiao et al. (2016) for the purpose of evaluationg two conditions in information sharing. Zapatero et al. (2016) employed confirmatory factor analysis method to try purchasing and marketing integration and evaluate the positive and negative sides among different integration mechanisms. Poper et al. (2016) attempted to develop a statistical evaluation based on innovation production function to explore the effects of designs to NPD performance.

The papers that proposed multicriteria decision making (MCDM) methods can be found in the second group. Büyüközkan and Feyzioğlu (2004) presented fuzzy analytical hierarchy process (FAHP) to succeed best decision making and reducing the uncertainty and changing information. Lo et al. (2006) introduced a new method that named idea screening by reducing the complexity of NPD process by relaxing the assumptions should be considered in this process. Kahraman et al. (2007) utilized hierarchical fuzzy TOPSIS method and fuzzy heuristic multiattribute utility method to make easier deciding rational selections. Chen et al. (2008) used analytical hierarchy process (AHP) with sensitivity analysis to have long term success in the company by executing NPD process successfully. Mazzola et al. (2008) attempted to develop a decision support system in order to structure interfirm relationship with their network partners in NPD process. Wang (2009) presented 2-tuple fuzzy linguistic computing approach to deal with the complexity of heterogeneous information and to prevent information loss during the process of integrating subjective opinions evaluations. Shen and Yu (2009) tried to find useful fuzzy MCDM approach by taking into account both strategic and operational factors to select the supply chain partners in the process of NPD. Chan and Ip (2011) proposed a decision support system that aims to predict customer purchasing behavior and net customer lifetime value. Ngan (2011) proposed 2-tuple fuzzy linguistic computing to aggregate opinions in the survey to evaluate the NPD in two different data set.

ANP was introduced by Chang (2013) for a Taiwanese food firm to make ideal decisions of managers for NPD project section. Hede et al. (2013) formed a multicriteria hierarchical model (MCHM) to provide design optimization in medicaldevice development. Ayağ (2014) combined ANP method with TOPSIS for solving concept selection problem. Yeh et al. (2014) applied multicriteria decision-making methods by utilizing critical success factors (CSF) and key performance indicators (KPI) to shed light on the critical factors of NPD. Yuen (2014) applied fuzzy quality function development (FQFD) to help the cloud software product development process. Recently, a hybrid MCDM model constructed by Chen et al. (2015) for a Taiwanese firm to evaluate $LiFePO_4$ battery product design. Dragincic and Korac (2015) proposed analytical hierarchy process (AHP) as a multicriteria decision making approach by combining Simple Additive Weighting (SAW) method to select most suitable table grape variety for a successful grape production to establish a vineyard.

In the third group, optimization methods were employed. Bhattacharya et al. (2003) applied a linear utility model to decide product positioning and introduction sequence in a firm. Maravelias and Grossman (2004) introduced a mixed integer linear programming model to provide installation of new resources without experiencing any problems and to make the testing process of new products by eradicating bottlenecks and outsourcing problems. Dragut (2006) presented a stochastic model by using lattice programming techniques to prevent the uncertainty due to time. Trappey and Chiang (2008) applied data envelopment analysis to optimize the resource planning and to provide profit maximization in an electric motor scooter design project. A mixed integer linear programming (MILP) was presented by Colvin and Maravelias (2009) for helping the schedule of clinical trials for the testing new products. Juan et al. (2009) introduced multiagent system (MAS) development methods on java agent development framework (JADE) to support the cooperation requirements in a CNPD process. Wang and Lin (2009) developed an overlapping process by minimizing the project delay risk so that a better process structure can form. Nishino et al. (2011) proposed a decision-making model by utilizing a game theoretic approach for production of electric vehicles. A system dynamics model was proposed by Lee and Wang (2012) to explore the R&D workloads on NPD systems under different supplier involvement situations. Yang et al. (2014) introduced a model within uncertainty theory to investigate the impacts of risk attitude on optimal wage contract mechanism and to find the information value of the idea and type of them. Ketunnen et al. (2015) attempted to develop a model by utilizing dynamic programming to a firm by involving the possibilities of facing different market environment. A product quality choice of a multinational automaker under different restrictions was modeled by Gouda et al. (2016) to provide appropriate decision making of automakers.

Also, there are some papers that exploratory case studies which have the main role in structuring and solving the problems. Gupta et al. (2007) used a comparative analysis between two case studies including biopharmaceutical and telecommunication industries to understand the dynamics of NPD in these industries. Caniato et al. (2014) developed 13 case studies from Italian fashion companies as the empirical method to provide integration of NPD and international retail by considering different characteristics of each country. Coenen and Kok (2014) presented five explatory case studies among Dutch firms to find a meaningful answer about the effects of telework and flexible work scheduling on the performance of NPD. Dain and Merminod (2014) employed 6 case studies to identify the different shaping of knowledge sharing according to different supplier involvement configuration (black, grey and white box). Gmelin and Seuring (2014) proposed 6 different case studies related to automotive manufacturing companies in order to explore the results of integrating product lifecycle management into NPD. Oh et al. (2015) utilized a practical case study for an NPD collaboration model that integrate product lifecycle management (PLM) and supply chain management (SCM) to provide effective work process that succeed shortening lead time. Sjoerdsma and Weele (2015) aimed to find a meaningful relationship between supplier relationship quality, knowledge transfer and NDP performance by using 4 case studies.

A complete list of these studies provided in Table 2.1:

Table 2.1: Literature review on new product development

Year	Author(s)	Method(s)
2003	Bhattacharya et al.	Matematical Modeling
2004	Büyüközkan and Feyzioğlu	FAHP
2004	Marvelias and Grossman	MILP
2006	Dragut	Lattice Programming
2006	Lo et al.	Idea Screening
2007	Gupta et al.	Comperative Analysis
2007	Kahraman et al.	Fuzzy TOPSIS
2007	Swink and Song	Path model approach
2008	Afonso et al.	Multiple linear regression
2008	Chen et al.	AHP
2008	Liao et al.	Apriori algorithm
2008	Mazzola et al.	DSS
2008	Trappey and Chiang	Data Envelopment Analysis
2009	Colvin and Marvelias	MILP
2009	Juan et al.	Multiagent System Dev.
2009	Shen and Yu	Herzberg's two factor theory
2009	Wang	2-tuple fuzzy linguistic
2009	Wang and Lin	Simulation
2011	Chan and Ip	DSS
2011	Ho and Tsai	SEM, ANFIS
2011	Ngan	2-tuple fuzzy linguistic
2011	Nishino et al.	Matematical modeling
2011	Tang et al.	Belief rule base generation
2012	Lee and Wang	System Dynamics
2013	Carbonel and Escudero	Path anaylsis

Year	**Author(s)**	**Method(s)**
2013	Chang	ANP
2013	Hede et al.	MCHM
2014	Ayağ	ANP, TOPSIS
2014	Caniato et al.	Contingency theory
2014	Chen et al.	Regression analysis
2014	Coenen and Kok	Regression analysis
2014	Dain and Merminod	Knowledge sharing
2014	Gmelin and Seuring	PLM
2014	Homburg and Kuehnl	Regression analysis
2014	Liang et al.	ANOVA
2014	Marmier et al.	Backward method
2014	Oehmen et al.	Goodman and Kruksal's gamma
2014	Rossi et al.	ANOVA
2014	Yang et al.	Uncertainity theory
2014	Yeh et al.	FAHP
2014	Yuen	Quality Function Deployment
2014	Zhao et al.	Confirmatory factor analysis
2015	Benedetto	MANOVA
2015	Chen et al.	Confirmatory factor analysis
2015	Dragincic and Korac	AHP
2015	Gonzalez et al.	Hierarhical regression analysis
2015	Gopalakrishnan et al.	ANCOVA
2015	Ketunnen et al.	Dynamic programming
2015	Lechler and Thomas	Path analysis, Multiple regression

Year	Author(s)	Method(s)
2015	Mazzola et al.	Eigenvector centrality
2015	Mu	Confirmatory factor analys
2015	Oh et al.	Integrated collaboration model
2015	Sjoerdsma and Weele	SRM
2016	Gouda et al.	Matematical modeling
2016	Poper et al.	Innovation production function
2016	Xiao et al.	Logistic regression
2016	Zapatero et al.	Confirmatory factor analysis

3. QUALITY FUNCTION DEPLOYMENT

Quality Function Deployment (QFD) was conceived in Japan in the 1970’s (Akao, 1990). A logistics system that is able to accomplish customer requirements wanted to be created by Kobe supertanker company. QFD was born in this manner. After the first employment of OFD, many other institutions comprising Motorola, HP, Kodak started to utilize QFD method (Iranmanesh and Thomson, 2008). Spreading of QFD to United States did not occur immediately after using in Japan. Approximately 10 years later, it became a recognizable method in the U.S.

QFD is a crucial approach that aims to response customer requirements in developing a new product. To accomplish customer requirements while producing a product is strictly depends on the capability of organizations. In these cases, QFD provides to find a common ground between customer requirements and capability of organizations and tries to get closer each other.

Customer requirements are the basis of QFD methodology. This methodology based on the idea of converting subjective customer terms into quantitive terms during the process of producing a product. In case of applying successfully, the cycle time can be reduced and the production cost can be decreased.

QFD methodology can be classified into four stages.

- Product planning
- Part deployment
- Process planning
- Production planning

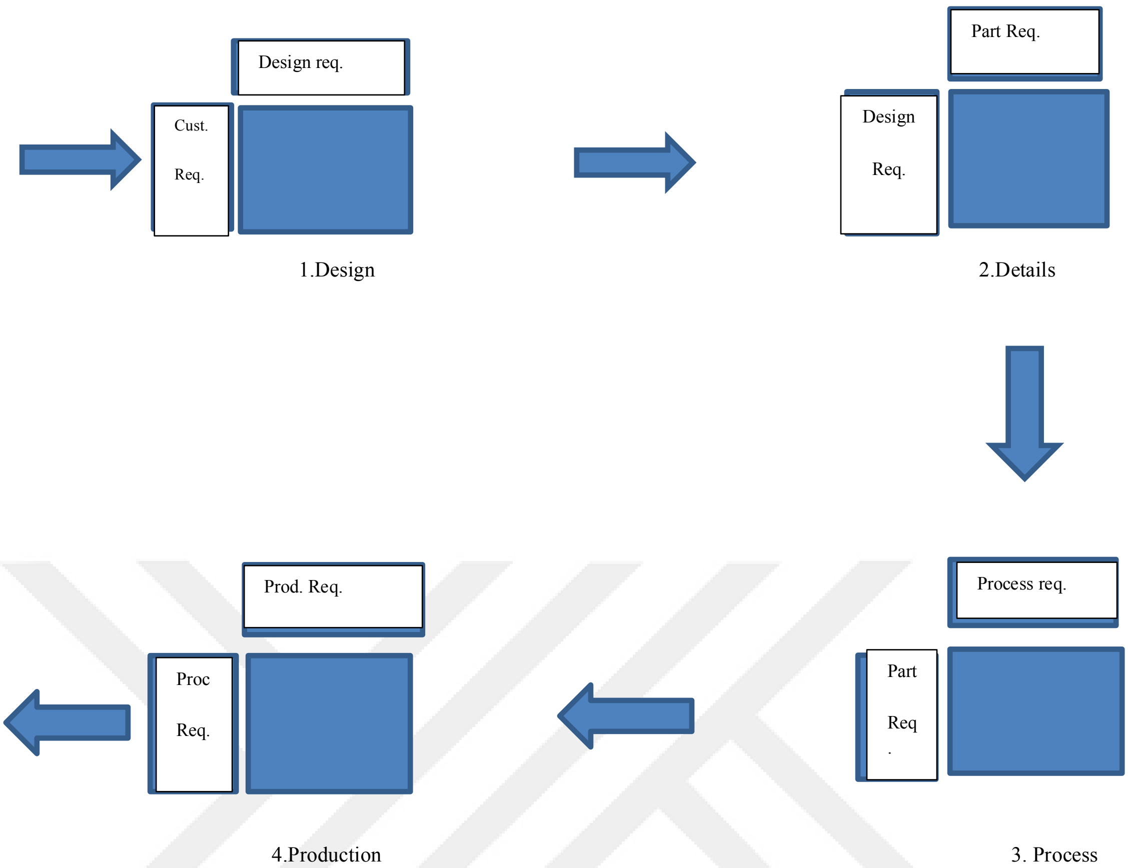


Figure 3.1: Phases of QFD process.

Product planning: This phase, which is also called the House of Quality (HOQ), includes getting enough and useful data from customers. Some specifications such as customer requirements, capacity of organizations are recorded in this phase. It is an important phase due to effecting whole QFD process.

Part deployment: Product concepts are decided and parts that is able to meet customer equirements are selected.

Process planning: In process planning phase, manufacturing processes are designated.

Production planning: In this phase, manufacturing operations are translated into production standards (Liu, Wang 2010).

3.1 The House of Quality

House of Quality (HOQ) is the basic diagram employed in QFD. The name of this chart comes from its appearance, its shape seems as a house. The HOQ includes seven component that each has a different function.

1. Customer Needs (CNs): The first step while composing HOQ is revealing necessities of customers. In this way, necessary characteristics of the product are determined.

2. Technical Attributes (TAs): TAs identify the product with the engineering perspective. CNs and TAs are two distinct points that evaluate the product with different languages.

3. Importance of CNs: The opinions of customers for the product that will develop should be rated according to their importance. In this way, it is desirable to stand out the most important points and to exclude less importants.

4. Relationships between CNs and TAs: The degree of impact of each TA on each CN is rated.

5. Competitive assessment matrix: This matrix is constructed by taking the customer opinions on a predetermined scale for the product from different companies for each CN.

6. Inner dependence among TAs: It forms the roof of HOQ matrix and indicates the dependencies among TAs.

7. Overall priorities of the TAs and additional goals: All steps applied so far are brought together and used to calculate the final ranking of TAs (Karsak and Dursun, 2015).

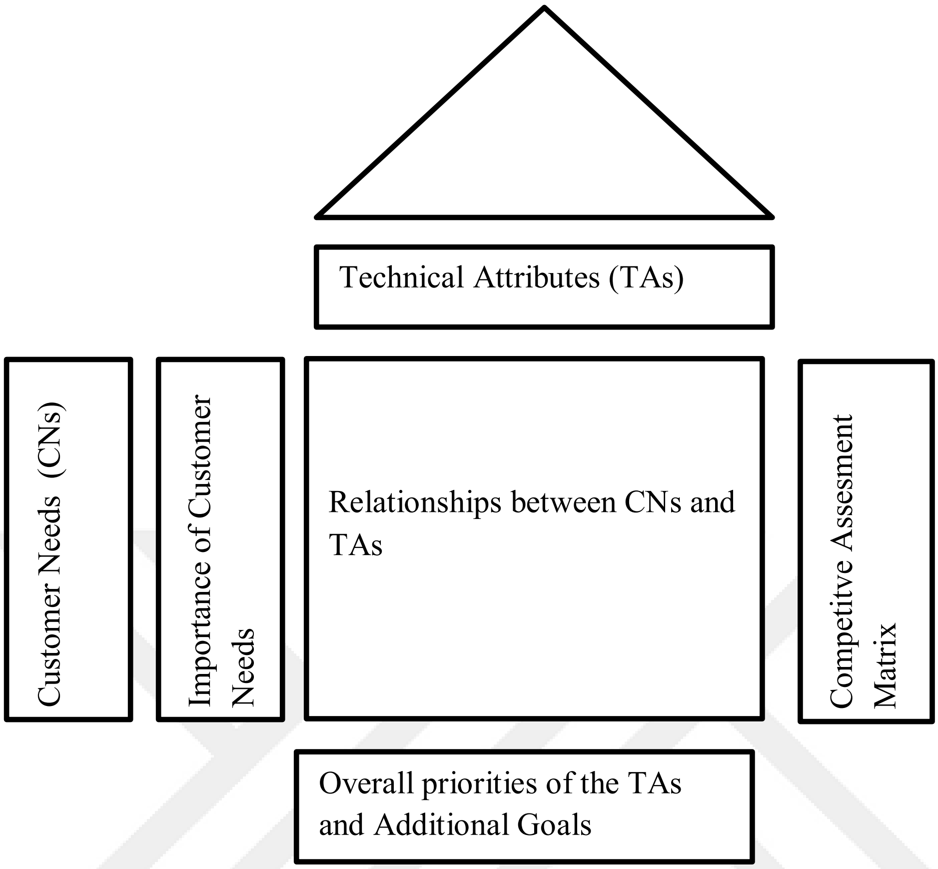


Figure 3.2: The house of quality

4. FUZZY SET THEORY

Fuzzy set theory, which was introduced firstly by Zadeh due to the aim of overcome the problems that involved ambiguity, has been used for embodying imprecise data into the decision framework.

A fuzzy set can be described as $\tilde{A}$ symbolically. $\mu_{\tilde{A}}(x)$ is a membership function that designates each element x in the universe of discourse X a real number in the interval [0,1]. It denotes the membership degree of the element in the language of fuzzy set theory.

Some essential explanations demonstrated below (Klir et al., 1997)

Definition1. A fuzzy set $\tilde{A}$ can be accepted as convex if and only if for all x_1 and $x_2 \in X$:

$$\mu_{\tilde{A}}(\lambda x_1 + (1-\lambda) x_2) \geq min\,(\mu_{\tilde{A}}(x_1), \mu_{\tilde{A}}(x_2)),\ \lambda \in [0,1] \tag{4.1}$$

Definition2. A fuzzy set $\tilde{A}$ is called a normal fuzzy set implying

$$\exists x_i \in X,\ \mu_{\tilde{A}}(x_i) = 1 \tag{4.2}$$

Definition3. α cut is described as $\tilde{A}_\alpha = \{x_i : \mu_{\tilde{A}}(x_i) \geq \alpha,\ x_i \in X\}$ where $\alpha \in [0,1]$ $\tilde{A}_\alpha$ is a limited nonempty bounded interval contained in X and it can be noted by $\tilde{A}_\alpha$ $\left[(\tilde{A})_\alpha^L, (\tilde{A})_\alpha^U\right]$, where $(\tilde{A})_\alpha^L$ and $(\tilde{A})_\alpha^U$ are the lower and higher bounds of the closed interval, respectively.

A triangular fuzzy number $\tilde{A}$ can be symbolized by a triplet (a1, a2, a3). The membership function $\mu_{\tilde{A}}(x)$ is classified as

$$\mu_{\tilde{A}}(x) = \begin{cases} \dfrac{x-a_1}{a_2-a_1}, a_1 \le x \le a_2 \\ \dfrac{x-a_3}{a_2-a_3}, a_2 \le x \le a_3 \\ 0, otherwise \end{cases} \tag{4.3}$$

Definition 4. If $\tilde{A}$ is a fuzzy number and $a_1^{\alpha} > 0$ for $\alpha \in [0,1]$, then $\tilde{A}$ is labeled as a positive fuzzy number.

Any two positive fuzzy numbers $\tilde{A}$ and $\tilde{B}$ and a positive real number *k*, the α - cuts of two fuzzy numbers are $\tilde{A}_{\alpha} = [(\tilde{A})_{\alpha}^{L}, (\tilde{A})_{\alpha}^{U}]$, and $\tilde{B}_{\alpha} = [(\tilde{B})_{\alpha}^{L}, (\tilde{B})_{\alpha}^{U}]$, respectively, where $(\alpha \in [0,1])$. The fundamental arithmetic operations in positive fuzzy numbers can be defined as follows:

$$(\tilde{A}(+)\tilde{B})_{\alpha} = \left\lfloor (A)_{\alpha}^{L} + (B)_{\alpha}^{L}, (A)_{\alpha}^{U} + (B)_{\alpha}^{U} \right\rfloor \tag{4.4}$$

$$(\tilde{A}(-)\tilde{B})_{\alpha} = \left\lfloor (A)_{\alpha}^{L} - (B)_{\alpha}^{L}, (A)_{\alpha}^{U} - (B)_{\alpha}^{U} \right\rfloor \tag{4.5}$$

$$(\tilde{A}_{\alpha})^{-1} = \left\lfloor \frac{1}{(A)_{\alpha}^{U}}, \frac{1}{(A)_{\alpha}^{L}} \right\rfloor \tag{4.6}$$

$$(\tilde{A}(*)k)_{\alpha} = \left\lfloor (A)_{\alpha}^{L} * k, (B)_{\alpha}^{U} * k \right\rfloor \tag{4.7}$$

$$(\tilde{A}(\div)k)_{\alpha} = \left\lfloor \frac{(A)_{\alpha}^{L}}{k}, \frac{(A)_{\alpha}^{U}}{k} \right\rfloor \tag{4.8}$$

Definition 5. If $\tilde{A}$ is a fuzzy number and $(A)_{a}^{L} > 0$, $(A)_{a}^{U} \le 1$ for $\alpha \in [0,1]$, then $\tilde{A}$ is called a normalized positive fuzzy number.

5. 2-TUPLE FUZZY LINGUISTIC REPRESENTATION MODEL

2-tuple fuzzy linguistic representation model was announced with the aim of advancing a different computational model of fuzzy linguistic approach. Linguistic information is symbolized by a pair of values (s_i, α) where s is a linguistic term from predefined linguistic term set S and α is a numerical value representing the symbolic translation (You et al., 2015). 2-tuple fuzzy linguistic representation model provides transformation between linguistic 2-tuples and numerical values by defining a set of functions.

For example, a set of five terms S to show the cleaning power of a cleaner can be symbolized as: $S = \{s_0, s_1, s_2, s_3, s_4\}$ that s_0, s_1, s_2, s_3, s_4 has a meaning of, “very low”, “low”, “medium”, “high”, “very high” respectively (Ju et al., 2012).

When compared to classical models, 2-tuple fuzzy linguistic representation model has some important advantages that can be listed below:

- 2 tuple fuzzy linguistic representation model achieves to transform information between different linguistic term sets without any loss.

- While the linguistic domain able to be acted as continuous, it is acted as discrete in classical models.

These positive influences make rational to use linguistic representation model.

Definition 1 (Herrera and Martinez, 2000): Let $L = (\gamma_0, \gamma_{1,\dots,} \gamma_g)$ is accepted as a fuzzy set defined in S_T. A transformation function χ that provides to transform L into numerical value in the interval of granularity of S_T, [0,g] can be described as

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

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

where $F(S_T)$ explains the set of fuzzy sets described in S_T. (5.1)

Definition 2 (Herrera and Martinez, 2000)**:** Let $S = \{s_0, s_1,\ldots,s_g\}$ is accepted as a lingustic term set and $\beta \in [0,g]$ accepted as a value that provide to support the result of a symbolic aggretion operation, then the 2-tuple that express the equivalent information to β is obtained with the function below:

$$\Delta : [0, g] \rightarrow S \times [-0.5, 0.5),$$
$$\Delta(\beta) = \begin{cases} s_i, & i = \text{round}(\beta) \\ \alpha = \beta - i, & \alpha \in [-0.5, 0.5) \end{cases} \qquad (5.2)$$

'round' is classical round operation, s_i means the closest index label to 'β', and 'α' means the value of the symbolic translation.

Example: Assume that a symbolic aggregation operation over labels assessed in $S = \{s_0, s_1, s_2, s_3, s_4\}$ that gives the result as $\beta = 3.7$. The representation in the language of 2-tuple will be:

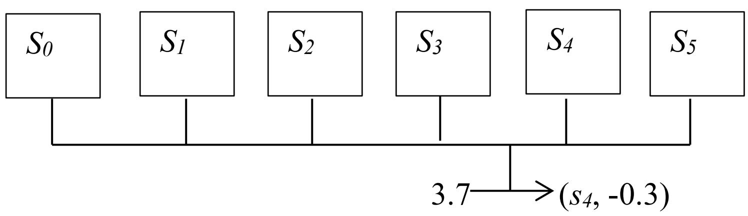


Figure 5.1: Example of 2- tuple representation

Proposition 1 (Herrera and Martinez, 2000): Let $S = \{s_0, s_1, \ldots, s_g\}$ is accepted 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 gives its identical numerical value $\beta \in [0,g] \subset \Re$. This function is described as

$\Delta^{-1}: S \times [-0.5, 0.5) \longrightarrow [0,g]$,

$\Delta^{-1}(s_i, \alpha) = i + \alpha = \beta$ (5.3)

Definition 3 (Herrera - Viedma et al., 2004): Let $\chi = \{(s_1, \alpha_1),..., (s_n, \alpha_n)\}$ is defined as a set of linguistic 2-tuples and $W = \{w_1,...,w_n\}$ be their associated weights. The 2-tuple weighted average x^{-w} can be calculated as

$$x^{-w}[(s_1, \alpha_1),..., (s_n, \alpha_n)] = \Delta\left(\frac{\sum_{i=1}^{n}\Delta^{-1}(s_i, \alpha_i).w_i}{\sum_{i=1}^{n} w_i}\right) = \Delta\left(\frac{\sum_{i=1}^{n}\beta_i.w_i}{\sum_{i=1}^{n} w_i}\right) \quad (5.4)$$

Definition 4 (Herrera-Viedma et al., 2004; Wang, 2010): Accept that $\chi = \{(s_1, \alpha_1),...,(s_n, \alpha_n)\}$ is a set of linguistic 2-tuples and $W = \{(w_1, \alpha_1^w),...,(w_n, \alpha_n^w)\}$ is their linguistic 2-tuples related with weights. The 2-tuple lingustic weighted average χ_l^{-w} is computed with the function below:

$$\chi_l^{-w}\ ([(s_1, \alpha_1),...,(w_1, \alpha_1^w)]...\ [(s_n, \alpha_n), (w_n, \alpha_n^w)]) = \Delta\left(\frac{\sum_{i=1}^{n}\beta_{i.}.\beta w_i}{\sum_{i=1}^{n}.\beta w_i}\right)$$

with $\beta_i = \Delta^{-1}(s_i, \alpha_i)$ and $\beta w_i = \Delta^{-1}(w_i, \alpha_i^w)$. (5.5)

Additionally, there are different operators described as follows:

1. 2- Tuple Comparison Operators

Comparision of lingustic represented by 2-tuples as follows:

Let (s_x, α_1) and (s_y, α_2) are accepted as 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 $(s_x, \alpha_1) > (s_y, \alpha_2)$

2. 2-Tuple Negotiation Operator

$Neg\ ((s_i, \alpha)) = \Delta\ (g - (\Delta^{-1}(s_i, \alpha)))$

Where $g + 1$ can be defined as cardinality of S. $S = \{s_o,...,s_g\}$. (5.6)

3. Different 2-tuple aggregation operators have been developed based on classical aggregation operators, for example, LOWA operator, the weighted average operator, the OWA operator, etc. (Li et al., 2014).

6. LINGUISTIC HIERARCHIES

The linguistic hierarchy (LH) can be defined as a set of levels that each level shows linguistic term set with different granularity from the remaining levels of the hierarchy (Herrera and Martinez, 2001). A level in this hierarchy can be symbolized as $l(t, n(t))$.

- t represents the level of hierarchy.
- $n(t)$ represents the granularity of the term set of the level t.

It is considered that linguistic terms' membership functions are triangular-shaped, symmetrical and uniformly distributed in [0,1].

The ordering of the levels in a linguistic hierarchy is implemented by taking into account their granularity. For instance, two successive levels t and $t + 1$, $n(t + 1) > n(t)$. With this way, the clarification of the previous level is provided.

Linguistic hierarchy can be described as the union of all levels t (Cordon et al.,2002).

$$LH = \cup_t (t, n(t)) \tag{6.1}$$

It is expressed that, the linguistic term set of a level is reached from its predecessor. For instance, linguistic term set of level $t + 1$ is obtained from t.

$$L(t, n(t)) \longrightarrow L(t + 1, 2n(t)\text{-}1) \tag{6.2}$$

Table 6.1: Linguistic Hierarchies

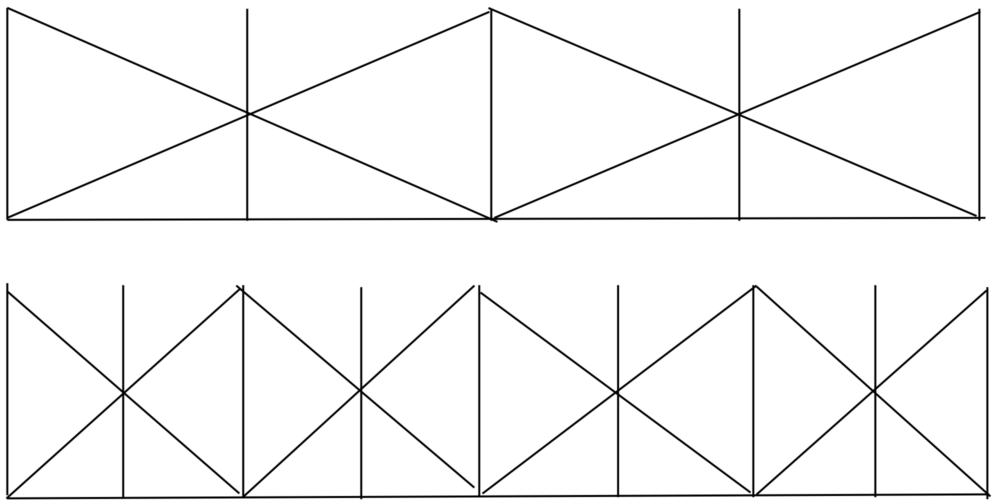
	Level 1	Level 2	Level 3	Level 4
L(*t*, *n(t)*)	L(1,2)	L(2,3)	L(3,5)	L(4,9)

Definition: Accept that $s^{n(t)} = \{s_0^{n(t)}, ..., s_{n(t)-1}^{n(t)}\}$ is a linguistic term set in the linguistic hierarchy that LH = $\cup_t$(*t*, *n(t)*). A transformation function from level *t* to a successive level *t* + c with c ϵ {-1,1}, can be formed as TF_{t+c}^{t} : *l*(*t*, *n(t)*) ⟶ *l*(*t* + *c*, *n*(*t* + *c*)) such that

$$TF_{t+c}^{t}\left(s_i^{n(t)}, \alpha^{n(t)}\right) = \Delta_{(t+c)}\left(\frac{\Delta_t^{-1}\left(s_i^{n(t)}, \alpha^{n(t)}\right)\left(n(t+c)-1\right)}{n(t)-1}\right). \tag{6.3}$$

The transformation function that defined was recurrently devoted to transform linguistic terms between any linguistic level involved in the linguistic hierarchy. Subsequently it has been described in a nonrecurring way, i.e., $TF_{t'}^{t}$: *l*(*t*, *n(t)*) ⟶ *l*(*t'*, *n*(*t'*)), such that

$$TF_{t'}^{t}\left(s_i^{n(t)}, \alpha^{n(t)}\right) = \Delta_{t'}\left(\frac{\Delta_t^{-1}\left(s_i^{n(t)}, \alpha^{n(t)}\right)\left(n(t')-1\right)}{n(t)-1}\right) \tag{6.4}$$



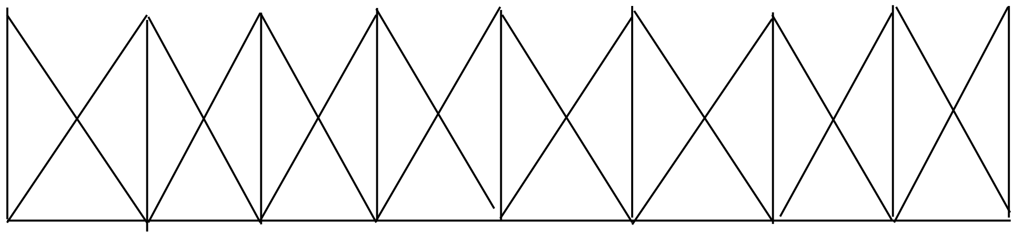


Figure 6.1: Linguistic Hierarchy of three, five and nine labels

Proposition: The transformation function between linguistic terms in disparate levels of the linguistic hierarchy can be defined as bijective.

$$TF_{t'}^{t}\left(TF_{t'}^{t}\left(s_i^{n(t)},\alpha^{n(t)}\right)\right)=\left(s_i^{n(t)},\alpha^{n(t)}\right) \tag{6.5}$$

This result guarantees that transformations between separate levels of a linguistic hierarchy are accomplished without loss of information.

7. FUZZY TOPSIS METHOD

It is a well-known fact that, to express the necessities, preferences and thoughts is not sufficient by using crisp numbers only. Fuzzy set theory was evolved to eliminate this limitation by allowing to model uncertainty of human judgments (Zadeh, 1965).

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a common method introduced by Huvang and Yoon (1981). This technique is typically used for solving MCDM problems. In TOPSIS method, two solutions are identified, ideal solution and anti- ideal solution. While ideal solution maximizes the benefit criteria and minimizes the cost criteria, anti-ideal solution maximizes the cost criteria and minimizes the benefit criteria. Because of this reason, the principal idea behind TOPSIS is, locating shortest distance to ideal solution and longest distance to anti-ideal solution.

While in classical TOPSIS, the ratings for criteria are known precisely, in fuzzy TOPSIS, the ratings for criteria are described in linguistic terms.

The steps for fuzzy topsis method is below (Taylan et al., 2016):

Step1: Average the fuzzy numbers. Equation (7.1) was used for averaging the fuzzy numbers. In the formula, z_{ij} are fuzzy numerical values assigned by the *k*-th decision maker, (+) expresses the fuzzy arithmetic summation function. $X = (\hat{z}_{ij})_{nxm}$ is a fuzzy decision matrix characterized by fuzzy numerical values.

$$\tilde{X}_{ij} = \frac{1}{N} \{\tilde{z}_{ij}^{(1)} + \tilde{z}_{ij}^{(2)} + \ldots + \tilde{z}_{ij}^{(N)}\} \quad (7.1)$$

The decision makers used fuzzy linguistic terms and then the terms were converted to fuzzy numerical values to evaluate different alternatives.

Step2: Linear normalization is an option to keep away from complex calculations. This normalization converts all homogenous data to the range of normalized triangular fuzzy numbers in the interval [0,1]. The normalized fuzzy decision matrix can be described as $\tilde{R}_{ij.}$ $\tilde{R}_{ij} = [\tilde{r}_{ij}]_{mxn}$, $i = 1,2,\ldots,m$; $j = 1,2,\ldots,n$.

where

$$\tilde{r}_{ij} = (\tilde{r}_{ij}^{l}\ \ \tilde{r}_{ij}^{m}, \tilde{r}_{ij}^{u}) = \left(\frac{z_{ij}^{l}}{c_j^*}, \frac{z_{ij}^{m}}{c_j^*}, \frac{z_{ij}^{u}}{c_j^*}\right), \quad i = 1, 2, 3, \ldots, m.\ j \in B. \tag{7.2}$$

$$\tilde{r}_{ij} = (\tilde{r}_{ij}^{l}\ \ \tilde{r}_{ij}^{m}, \tilde{r}_{ij}^{u}) = \left(\frac{c_j^-}{z_{ij}^{l}}, \frac{c_j^-}{z_{ij}^{m}}, \frac{c_j^-}{z_{ij}^{u}}\right), \quad i = 1, 2, 3, \ldots, m.\ j \in C. \tag{7.3}$$

$$c_j^* = \max_t\ [z_{ij}^u],\ j = 1, 2, 3, \ldots, n. \tag{7.4}$$

$$c_j^- = \min_t\ [z_{ij}^l],\ j = 1, 2, 3, \ldots, n. \tag{7.5}$$

Eq. (7.4) is utilized to find the maximum value of (c_j^*) for each alternative. The weighted normalized fuzzy decision matrix ($\tilde{V}$) can then be computed by using Eq. (7.6).

$\tilde{V} = [\tilde{v}_{ij}]_{mxn}$, $i = 1,2, \ldots, m$; $j = 1, 2,.., n.$ where,

$$\tilde{v}_{ij} = (v_{ij}^l, v_{ij}^m, v_{ij}^u) = w_j \otimes \tilde{r}_{ij} = (w_j^l r_{ij}^l, w_j^m r_{ij}^m, w_j^u r_{ij}^u) \tag{7.6}$$

Accordingly, the fuzzy ideal solution and the fuzzy anti ideal solution denoted by $A^*$and A^- can be found by the way below:

$A^* = (v_1^*, v_2^*, \ldots, v_n^*)$

$A^- = (v_1^-, v_2^-, ..., v_n^-)$

$\tilde{v}^*_{(j)} = (\tilde{v}^*_1, \tilde{v}^*_2, \ldots, \tilde{v}^*_n),$

$\tilde{v}^-_{(j)} = (\tilde{v}^-_1, \tilde{v}^-_2, \ldots, \tilde{v}^-_n),$ where

$\tilde{v}^*_j = (1,1,1)$ and $\tilde{v}^-_j = (0,0,0)$, $j = 1,2,\ldots,n$.

$\tilde{v}^*_{(1,\ldots,6)}$ =[(1,1,1), (1,1,1), (1,1,1), (1,1,1), (1,1,1), (1,1,1)]

$\tilde{v}^-_{(1,\ldots,6)}$= [(0,0,0), (0,0,0), (0,0,0), (0,0,0), (0,0,0), (0,0,0)].

Step 3: The fuzzy ideal distances and fuzzy anti-ideal distances of alternatives is determined by the equations below:

$$d_i^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}^*_j), \quad i = 1,2,\ldots,m, \tag{7.7}$$

$$d_i^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, \tilde{v}^-_j), \quad i = 1,2,\ldots,m. \tag{7.8}$$

$d\left(d_i^*, d_i^-\right)$ is the distance between two fuzzy values that provides to calculate the closeness coefficient (CC_i). It is used to clarify the performance ranking of the alternatives. The rankings of alternatives can be found according to the result of closeness coefficient.

$$CC_i = \frac{d_i^-}{d_i^* + d_i^-} \quad i = 1,2,\ldots,m. \tag{7.9}$$

8. PROPOSED DECISION-MAKING ALGORITHM

This section represents the fuzzy group decision-making methodology, which employed QFD, linguistic hierarchies, 2-tuple fuzzy linguistic representation model and fuzzy TOPSIS method. The detailed stepwise representation of the proposed algorithm is shown in two part. While in the first part, QFD, linguistic hierarchies and 2-tuple fuzzy linguistic representation model are utilized, in second part fuzzy TOPSIS method is utilized and the result is obtained.

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 denotes the weights of each CNs, $\tilde{w}_{iz}$, relationships among CNs and TAs, $\tilde{x}_{ijz}$, inner dependencies among TAs, $\tilde{y}_{kjz}$ and ratings of alternatives with respect to each TA.

Step 3. Unify the multigranular linguistic information given by the decision-makers into a linguistic term set employing Eq. (6.3).

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 by using Eq. (5.1).

Step 6. Calculate the original relationship measure between the jth TA and the ith CN, $\tilde{x}_{ij}^*$, employing Eq. (5.5).

Step 7. Compute the 2-tuple linguistic weighted average for each TA.

Step 8. Aggregate fuzzy ratings of alternatives by using arithmetic mean operator.

Step 9: Employ fuzzy TOPSIS method for ranking alternatives by considering the computed 2-tuple linguistic weighted average at step 7 as the weights of TAs.

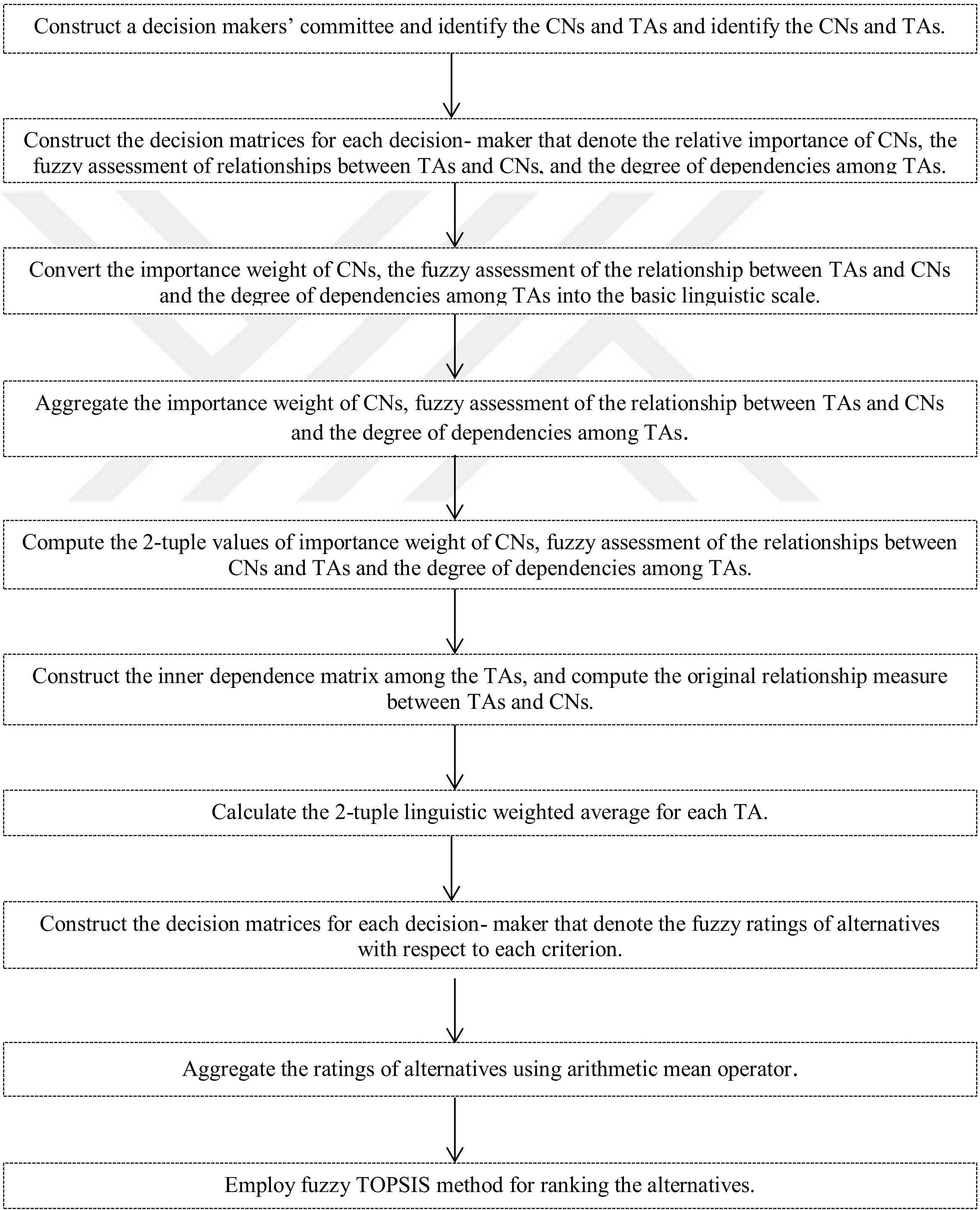


Figure 8.1 Illustration of the proposed fuzzy decision-making algorithm

9. CASE STUDY

The application of the proposed methodology is illustrated through a case study conducted in a detergent manufacturer factory located in south part of 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 then the features of washing liquids, expectations of customers, factors that effects on production process are stated. A survey is constructed with the contribution of quality control department finally.

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 9.1, is considered as multigranular linguistic context since the granularity of its linguistic term sets is very common in decision-making problems.

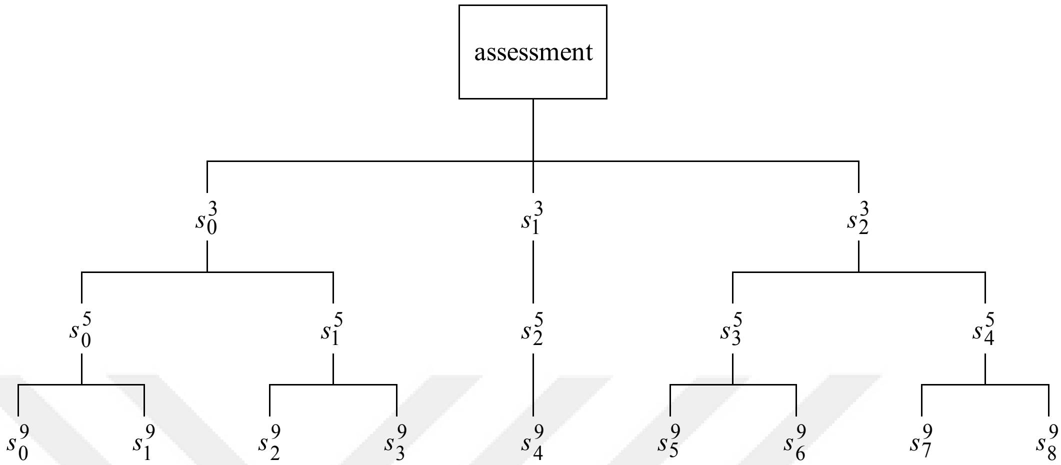


Figure 9.1 Multigranular linguistic context

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 ratings of four decision makers are presented below:

Table 9.1: The ratings of DMs to CN & TA relationship

	TA_1	TA_2	TA_3	TA_4	TA_5
CN_1	$(s_0^3,s_1^5,s_1^5,s_2^9)$	$(s_0^3,s_1^5,s_2^5,s_2^9)$	$(s_1^3,s_3^5,s_3^5,s_6^9)$	$(s_2^3,s_4^5,s_4^5,s_7^9)$	$(s_2^3,s_3^5,s_4^5,s_7^9)$
CN_2	$(s_1^3,s_3^5,s_2^5,s_5^9)$	$(s_0^3,s_1^5,s_1^5,s_2^9)$	$(s_2^3,s_3^5,s_4^5,s_7^9)$	$(s_2^3,s_3^5,s_4^5,s_6^9)$	$(s_1^3,s_4^5,s_3^5,s_7^9)$
CN_3	$(s_0^3,s_1^5,s_1^5,s_3^9)$	$(s_1^3,s_2^5,s_2^5,s_3^9)$	$(s_2^3,s_4^5,s_3^5,s_7^9)$	$(s_1^3,s_3^5,s_3^5,s_6^9)$	$(s_1^3,s_3^5,s_4^5,s_6^9)$
CN_4	$(s_0^3,s_1^5,s_0^5,s_2^9)$	$(s_2^3,s_3^5,s_2^5,s_5^9)$	$(s_2^3,s_3^5,s_4^5,s_8^9)$	$(s_2^3,s_3^5,s_4^5,s_7^9)$	$(s_2^3,s_3^5,s_4^5,s_6^9)$
CN_5	$(s_2^3,s_3^5,s_3^5,s_7^9)$	$(s_1^3,s_2^5,s_3^5,s_4^9)$	$(s_2^3,s_3^5,s_3^5,s_6^9)$	$(s_2^3,s_3^5,s_3^5,s_6^9)$	$(s_1^3,s_3^5,s_4^5,s_5^9)$

Table 9.2: The ratings of DMs to importance of CNs

	Importance of CNs
CN_1	$(s_1^3, s_3^5, s_2^5, s_6^9)$
CN_2	$(s_2^3, s_4^5, s_3^5, s_7^9)$
CN_3	$(s_2^3, s_3^5, s_4^5, s_6^9)$
CN_4	$(s_1^3, s_3^5, s_2^5, s_6^9)$
CN_5	$(s_2^3, s_4^5, s_3^5, s_7^9)$

Table 9.3: The ratings of DMs to TA& TA relationship

	TA_1	TA_2	TA_3	TA_4	TA_5
TA_1	-	$(s_2^3, s_3^5, s_2^5, s_6^9)$	$(s_0^3, s_1^5, s_2^5, s_3^9)$	$(s_0^3, s_1^5, s_1^5, s_3^9)$	$(s_1^3, s_2^5, s_2^5, s_4^9)$
TA_2	$(s_2^3, s_3^5, s_2^5, s_6^9)$	-	$(s_2^3, s_3^5, s_4^5, s_7^9)$	$(s_1^3, s_4^5, s_3^5, s_6^9)$	$(s_2^3, s_4^5, s_4^5, s_8^9)$
TA_3	$(s_0^3, s_1^5, s_2^5, s_3^9)$	$(s_2^3, s_3^5, s_4^5, s_7^9)$	-	$(s_1^3, s_2^5, s_3^5, s_6^9)$	$(s_2^3, s_4^5, s_3^5, s_6^9)$
TA_4	$(s_0^3, s_1^5, s_1^5, s_3^9)$	$(s_1^3, s_4^5, s_3^5, s_6^9)$	$(s_1^3, s_2^5, s_3^5, s_6^9)$	-	$(s_2^3, s_3^5, s_3^5, s_7^9)$
TA_5	$(s_1^3, s_2^5, s_2^5, s_4^9)$	$(s_2^3, s_4^5, s_4^5, s_8^9)$	$(s_2^3, s_4^5, s_3^5, s_6^9)$	$(s_2^3, s_3^5, s_3^5, s_7^9)$	-

The unified assessments of decision-makers are aggregated employing arithmetic mean operator and the results are given in Figure 9.2. The original relationship measure between CNs and TAs is calculated and the results are presented in Table 9.4.

Table 9.4: Original relationship between CNs and TAs

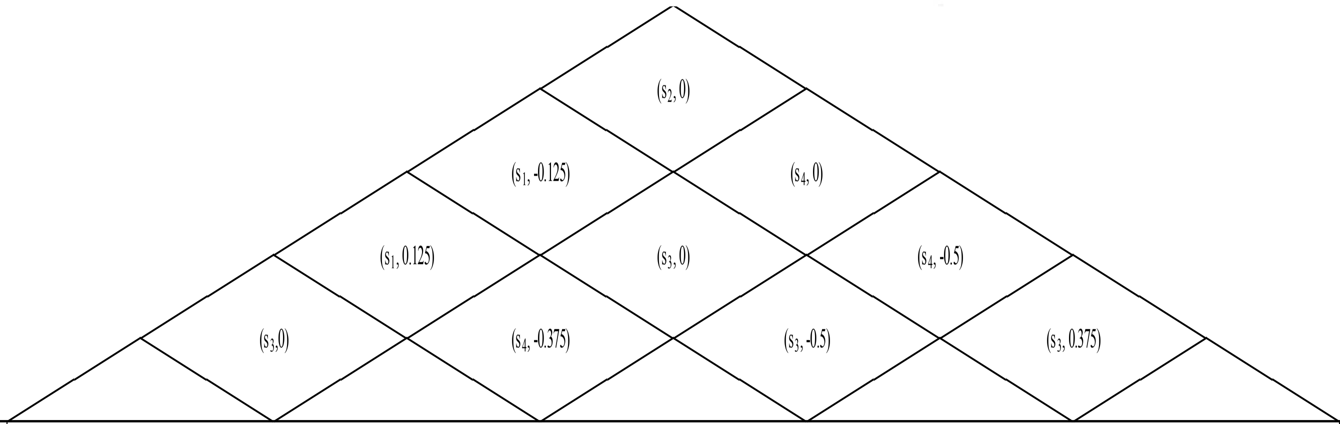
	TA_1	TA_2	TA_3	TA_4	TA_5
CN_1	(s_2, -0.21)	(s_2, 0.40)	(s_3, -0.43)	(s_3, -0.22)	(s_3, -0.47)
CN_2	(s_2, 0.29)	(s_3, -0.37)	(s_3, -0.32)	(s_3, -0.24)	(s_3, -0.35)
CN_3	(s_2, -0.04)	(s_2, 0.47)	(s_3, -0.31)	(s_3, -0.34)	(s_3, -0.44)
CN_4	(s_2, 0.27)	(s_3, -0.08)	(s_3, 0.21)	(s_3, 0.26)	(s_3, 0.07)
CN_5	(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 which told in section 5. The results are given in Table 9.5.

Table 9.5: 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)

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. In this way, weights of TAs are determined. After this determination, the ingredients of 6 formulations are given to DMs and the linguistic ratings of DMs to each formulation according to TAs are taken to use in fuzzy TOPSIS method. From now on, there are 3 decision makers instead of 4 decision maker.



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	$(s_3, 0.375)$	$(s_2, 0.25)$	$(s_2, 0.375)$	$(s_3, 0.25)$	$(s_3, -0.125)$	$(s_4, -0.375)$

Figure 9.2 Unified assesment of decision makers

Table 9.6: The ingredients of formulations

Formulation1	Formulation2	Formulation3	Formulation4	Formulation5	Formulation6
Water (Deionized) (82,4600)	Water (Deionized) (77.9275 kg.)	Water (Deionized) (77.9275 kg.)	Water (Deionized) (76.6175 kg.)	Water (Deionized) (76.6175kg.)	Water (Deionized) (82,4600)
Sodium Hydroxide (2.8000 kg.)	Sodium Hydroxide (1.500 kg.)	Sodium Hydroxide (1.7500 kg.)	Sodium Hydroxide (2.8000 kg.)	Sodium Hydroxide (2.8000 kg.)	Sodium Hydroxide (2,8000 kg.)
Labsa (11.3400 kg.)	Sles (15.7200 kg.)	Sles (15.7200 kg.)	Labsa (3.7000 kg.)	Labsa (3.7000 kg.)	Labsa (11.3400 kg.)
Coco Dietanolamid (2.0000 kg.)	Coco Dietanolamid (2.0000 kg.)	Coco Dietanolamid (2.0000 kg.)	Sles (13.48 kg.)	Sles (13.48 kg.)	Coco Dietanolamid (2.0000 kg.)
Kathon Cg (0.1000 kg.)	Kathon Cg (0.1000 kg.)	Formalin (0,1000 kg.)	Coco Dietanolamid (2.0000 kg.)	Coco Dietanolamid (2.0000 kg.)	Formalin (0.1000 kg.)
Dye Tartrazine (0.0025 kg.)	Dye Iragon Blue (0.0025 kg.)	Dye Tartrazine (0.0025kg.)	Kathon Cg (0.1000 kg.)	Formalin (0.1000 kg.)	Dye Tartrazine (0.0013 kg.)
NaCl (1.0000 kg.)	NaCl (2.2000 kg.)	NaCl (2.2000kg)	Dye Tartrazine (0.0025kg.)	Dye Tartrazine (0.0025kg.)	Dye Pyranin (0.0012 kg.)
Parfum. Lemon (0.3000 kg.)	Parfum Apple (0.3000 kg.)	Parfum Lemon (0.3000 kg.)	NaCl (1.0000 kg.)	NaCl (1.0000 kg.)	NaCl (1.0000 kg.)
			Parfum Lemon (0.3000 kg.)	Parfum Lemon (0.3000 kg.)	Parfum Lemon (0.3000 kg.)
Total: 100.00 kg	Total: 100.00 kg	Total: 100.00 kg	Total: 100.00 kg	Total: 100.00 kg	Total: 100.00 kg

Table 9.7: Linguistic ratings of DMs for formulations

	TA_1	TA_2	TA_3	TA_4	TA_5
F_1	(H,M,H)	(H,H,M)	(VH,H,M)	(VH,H,M)	(VH,H,M)
F_2	(H,M,M)	(M,M,L)	(M,M,M)	(H,M,L)	(M,M,L)
F_3	(M,L,M)	(M,M,H)	(H,H,M)	(H,M,M)	(M,H,M)
F_4	(H,M,H)	(H,VH,H)	(H,M,H)	(M,H,H)	(H,M,M)
F_5	(M,M,M)	(VH,H,M)	(H,L,M)	(H,H,M)	(M,L,L)
F_6	(H,M,H)	(M,H,H)	(M,M,H)	(L,M,M)	(M,H,M)

The linguistic ratings are converted to fuzzy numbers by employing the values presented in Table 9.8. The results are given accordingly, in Table 9.9.

Table 9.8: Fuzzy terms and their numerical values

Fuzzy linguistic terms for decision making	Fuzzy numerical values
Very Low (VL)	(0, 0, 0.25)
Low (L)	(0, 0.25, 0.50)
Average(A)	(0.25, 0.50, 0.75)
High(H)	(0.50, 0.75, 1)
Very High(VH)	(0.75, 1, 1)

The fuzzy presented in the Table 9.10 numbers are averaged by using the Eq. (7.1) and a normalized fuzzy decision matrix that is obtained.

Table 9.9: The fuzzy values of ratings of DMs

	TA_1	TA_2	TA_3	TA_4	TA_5
F_1	(0.5, 0.75, 1), (0.25, 0.5, 0.75), (0.5, 0.75	(0.5, 0.75, 1), (0.5, 0.75, 1), (0.25, 0.5,0.75)	(0.75, 1, 1), (0.5, 0.75, 1), (0.25, 0.5, 0.75)	(0.75, 1, 1), (0.5, 0.75, 1), (0.25,0.5,0.75)	(0.75, 1, 1), (0.5, 0.75, 1), (0.25, 0.5, 0.75)
F_2	(0.5, 0.75, 1), (0.25, 0.5, 0.75), (0.25, 0.5, 0.75)	(0.25, 0.5, 0.75), (0.25, 0.5,1) 0.75), (0, 0.25, 0.5)	(0.25, 0.5, 0.75), (0.25, 0.5, 0.75), (0.25, 0.5, 0.75)	(0.5, 0.75, 1), (0.25, 0.5, 0.75), (0, 0.25, 0.5)	(0.25, 0.5, 0.75), (0.25, 0.5, 0.75), (0, 0.25, 0.5)
F_3	(0.25, 0.5, 0.75), (0, 0.25, 0.5), (0.25, 0.5, 0.75)	(0.25, 0.5, 0.75), (0.25, 0.5, 0.75), (0.5, 0.75, 1)	(0.5, 0.75, 1), (0.5, 0.75, 1), (0.25, 0.5, 0.75)	(0.5, 0.75, 1), (0.25, 0.5, 0.75), (0.25, 0.5, 0.75)	(0.25, 0.5, 0.75), (0.5, 0.75, 1), (0.25, 0.5, 0.75)
F_4	(0.5, 0.75, 1), (0.25, 0.5, 0.75), (0.25, 0.75, 1)	(0.5, 0.75, 1), (0.75, 1, 1), (0.5, 0.75, 1)	(0.5, 0.75, 1), (0.25, 0.5, 0.75), (0.5, 0.75, 1)	(0.25, 0.5, 0.75), (0.5, 0.75, 1), (0.5, 0.75, 1)	(0.5, 0.75, 1), (0.25, 0.5, 0.75), (0.25, 0.5, 0.75)
F_5	(0.25, 0.5, 0.75), (0.25, 0.5, 0.75), (0.25, 0.5, 0.75)	(0.75, 1, 1), (0.5, 0.75, 1), (0.25, 0.5, 0.75)	(0.5, 0.75, 1), (0, 0.25, 0.5), (0.25, 0.5, 0.75)	(0.5, 0.75, 1), (0.5, 0.75, 1), (0.25, 0.5, 0.75)	(0.25, 0.5, 0.75), (0, 0.25, 0.5), (0, 0.25, 0.5)
F_6	(0.5, 0.75, 1), (0.25, 0.5, 0.75), (0.5, 0.75, 1)	(0.25, 0.5, 0.75), (0.5, 0.75, 1), (0.5, 0.75, 1)	(0.25, 0.5, 0.75), (0.25, 0.5, 0.75), (0.5, 0.75, 1)	(0, 0.25, 0.5), (0.25, 0.5, 0.75), (0.25, 0.5, 0.75)	(0.25, 0.5, 0.75), (0.5, 0.75, 1), (0.25, 0.5, 0.75)

Table 9.10: Normalized fuzzy decision matrix

	TA_1	TA_2	TA_3	TA_4	TA_5
F_1	(0.455, 0.727, 1)	(0.455, 0.727, 1)	(0.545, 0.818, 1)	(0.545, 0.818, 1)	(0.545, 0.818, 1)
F_2	(0.4, 0.7, 1)	(0.2, 0.501, 0.801)	(0.3, 0.6, 0.9)	(0.3, 0.6, 0.9)	(0.2, 0.501, 0.801)
F_3	(0.182, 0.455, 0.727)	(0.363, 0.636, 0.908)	(0.455, 0.727, 1)	(0.363, 0.636, 0.908)	(0.363, 0.636, 0.908)
F_4	(0.417, 0.667, 0.917)	(0.583, 0.833, 1)	(0.417, 0.667, 0.917)	(0.417, 0.667, 0.917)	(0.333, 0.583, 0.833)
F_5	(0.273, 0.545, 0.818)	(0.545, 0.818, 1)	(0.273, 0.545, 0.818)	(0.455, 0.727, 1)	(0.091, 0.363, 0.636)
F_6	(0.455, 0.727, 1)	(0.455, 0.727, 1)	(0.363, 0.636, 0.182)	(0.182, 0.455, 0.727)	(0.363, 0.636, 0.908)

Weighted normalized matrix is obtained after converting the weights of TAs which was found in first part to normalized weight in the interval [0,1]. The results are presented in the Table 9.11.

Table 9.11: Weighted normalized matrix

	TA_1	TA_2	TA_3	TA_4	TA_5
F_1	(0.082, 0.131, 0.18)	(0.095, 0.152, 0.209)	(0.119, 0.179, 0.218)	(0.097, 0.145, 0.178)	(0.117, 0.176, 0.215)
F_2	(0.072, 0.126, 0.18)	(0.042, 0.105, 0.168)	(0.066, 0.131, 0.197)	(0.053, 0.107, 0.16)	(0.043, 0.107, 0.172)
F_3	(0.033, 0.082, 0.131)	(0.076, 0.133, 0.19)	(0.099, 0.159, 0.218)	(0.064, 0.113, 0.161)	(0.08, 0.136, 0.195)
F_4	(0.075, 0.12, 0.165)	(0.122, 0.174, 0.209)	(0.091, 0.146, 0.2)	(0.074, 0.118, 0.163)	(0.071, 0.125, 0.179)
F_5	(0.049, 0.098, 0.147)	(0.114, 0.171, 0.209)	(0.06, 0.119, 0.179)	(0.08, 0.129, 0.178)	(0.019, 0.078, 0.136)
F_6	(0.082, 0.131, 0.18)	(0.095, 0.152, 0.209)	(0.079, 0.139, 0.198)	(0.032, 0.08, 0.129)	(0.078, 0.136, 0.195)

Ideal solution and anti-ideal solution are calculated by using Eq. (7.7) . $\tilde{v}_j^* = (1,1,1)$ and $\tilde{v}_j^- = (0,0,0)$ values are accepted in our case. Finally closeness coefficient (CC_i) are calculated by using the Eq. 7.9. The results are presented Table 9.12.

Table 9.12: The results of closeness coefficent of formulations and their rankings.

Formulations	d_i^*	d_i^-	(CC_i)	Rank
1	7.344	1.159	0.136	2
2	7.673	1.086	0.124	5
3	7.59	1.147	0.131	4
4	7.494	1.213	0.139	1
5	7.649	1.019	0.118	6
6	7.564	1.172	0.134	3

According to the result of the analysis, Formulation 4 is determined best alternative washing liquid which is followed by Formulation1, Formulation6, Formulation3, Formulation2 and Formulation 5, respectively.

10. CONCLUSION

In rapidly changing manifacturing sector, remaining competitive is strictly depends on optimizing the business process. While producing a product, always taking correct steps is vital. To make an inappropriate or incorrect decision may lead to big damages that can not be compensated and finally fail all process.

Decision making is a familiar problem that is experienced in all stage of life. Material selection can be stated as an important decision making problem. To form a product that shows maximum performance at minumum cost is a sign of succesful material selection process.

Beyaz Kağıt is a detergent manufacturer factory that was founded in 2005 in Adana, south parth of Turkey. Peros, Asperox, Sev and Halk branded products are produced and brought to customer. Beyaz Kağıt contributes positively to the our country's economy, by marketing its products to Middle East, Africa, Balkans and Turkic Republics, 1500 tons detergent in a day can be produced in this factory. Thus, it is ranked among first 5 detergent manufacturers in Turkey.

In this thesis, a fuzzy multi-criteria decision making algorithm, which combine 2-tuple fuzzy linguistic modeling, linguistic hierarchies and quality function deployment was proposed to determine the importance of selection criteria in material selection procedure. After obtaining the importance of selection criteria, by employing fuzzy TOPSIS method, the most appropriate detergent that meets the needs among 6 alternatives was determined.

An analysis was conducted with 4 decision makers from different departments at Beyaz Kağıt. TAs were determined as "pH (TA_1)", "viscosity (TA_2)", "anionic active material (TA_3)", "nonionic active material (TA_4)", "total active material (TA_5)". After calculations, "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. Then, fuzzy TOPSIS method was employed by considering 3 decision makers' linguistic ratings. After the analysis, while Formulation 4 was found most appropriate washing liquid, Formulation 5 was found worst alternative among 6 washing liquid formulations.

Future research directions might focus on employing the proposed decision making approach to real world decision making problems in diverse disciplines

REFERENCES

Afonso, P., Nunes, M., Paisana, A. and Braga, A. (2008). The influence of time-to-market and target costing in the new product development success. *Int. J. Production Economics* 115, 559-568.

Akao, Y. (1990). Quality Function Deployment, Productivity Press. *Cambridge MA, Becker Associates Inc*

Ayağ, Z. (2014). An integrated approach to concept evaluation in a new product development, *Journal of Intelligent Manufacturing 27,* 1-15.

Bhattacharya, S., Krishnan, V. and Mahajan, V. (2003). Operationalizing technology improvements in product development decision-making. *European Journal of Operational Research* 149, 102-130.

Brown, S. L. and Eisenhardt, K. M. (1995). Product development: Past research, present findings and future directions. *Academy of Management Review* 20, 343–378.

Büyüközkan, G. and Feyzioğlu, O. (2004). A fuzzy-logic-based decision-making approach for new product development. *Int. J. Production Economics* 90, 27-45.

Caniato, F., Caridi, M., Moretto, A., Sianesi, A. and Spina, G. (2014). Integrating international fashion retail into new product development. *Int. J. Production Economics,* 147, 294-30.

Carbonell, P. and Escudero A. I. R. (2013). Management control, role expectations and job satisfaction of new product development teams: The moderating effect of participative decision-making. *Industrial Marketing Management* 42, 248-259.

Chan, S. L. and Ip, W. H. (2011). A dynamic decision support system to predict the value of customer for new product development, *Decision Support Systems* 52, 178-188.

Chang, K. L. (2013) . Combined MCDM approaches for century-old Taiwanese food firm new product development project selection. *British Food Journal 115*, 1197 - 1210

Chen, C. J., Liu, T. C., Chu, M. and Hsiao, Y. (2014). Intellectual capital and new product development. *J. Eng. Technol. Manage.* 33, 154-173.

Chen, J., Neubaum, D. O., Reilly, R. R. and Lynn, G. S. (2015). The relationship between team autonomy and new productdevelopment performance under different levels of technological turbulence. *Journal of Operations Management* 33-34, 83-9.

Chen, H. H., Kang, Y. H., Xing, X., Lee, H. I. A. and Tong, Y. (2008). Developing new products with knowledge management methods and process development management in a network. *Computers in Industry* 59, 242-253.

Coenen, M. and Kok, R. A. W. (2014). Workplace flexibility and new product development performance: The role of telework and flexible work schedules. *European Management Journal* 32, 564-576.

Colvin, M. and Maravelias, T. C. (2009). Scheduling of testing tasks and resource planning in new product development using stochastic programming. *Computers and Chemical Engineering* 33, 964-976.

Cooper, R. G. (2003). Perspective: Third generation new product processes. *Journal of Product Innovation Management* 11, 3–14.

Cordon, O., Herrera, F. and Zwir, I. (2002). Linguistic modeling by hierarchical systems of linguistic rules. *IEEE T. Fuzzy Syst*, 10(1), 2-20.

Dain, M. A. and Merminod, V. (2014). A knowledge sharingframework for black, grey and white box supplier configurations in new product development. *Technovation* 34, 688-701.

Dragincic, J. and Korac, N. (2015). Group multi-criteria decision making (GMCDM) approach for selecting the most suitable table grape variety intended for organic viticulture. *Computers and Electronics in Agriculture 111*, 194-202.

Dragut A. B. (2006). Monotonic Robust Optimal Control Policies for the Time-Quality Trade-Offs in Concurrent New Product Development (NPD). *Computers and Mathematics with Applications* 51, 229-238.

Genç, E. And Benedetto C. A. (2015). Cross-functional integration in the sustainable new product development process: The role of the environmental specialist. *Industrial Marketing Management 50,* 150–161.

Gmelin, H. and Seuring, S. (2014). Achieving sustainable new product development by integrating product life-cycle management capabilities. *Int. J.Production Economics* 154,166-177.

Gonzalez, J. G., Saez, P. L. and Lopez, J. E. N. (2015). Absorbing knowledge from supply-chain, industry and science: The distinct moderating role of formal liaison devices on new product development and novelty. *Industrial Marketing Management* 47, 75-85.

Gopalakrishnan, M., Libby, T., Samuels, J. A. and Swenson, D. (2015). The effect of cost goal specificity and new product development process on cost reduction performance. *Accounting, Organizations and Society* 42, 1-11.

Gouda, S. K., Jonnalagedda, S. and Saranga, H. (2016). Design for the environment: Impact of regulatory policies on product development. *European Journal of Operational Research* 248, 558-570.

Gupta, A., Pawar, K. S. and Smart, P. (2007). New product development in the pharmaceutical and telecommunication industries: A comparative study. *Int. J. Production Economics* 106, 41-60

Herrera, E., Herrera, F., Martinez, L., Herrera, J. C. and Lopez, A. G. (2004). Incorparating filtering tecniques in a fuzzy linguistic multi-agent model for information gathering on the web. *Fuzzy Sets ans Systems*, 148(1), 61-83.

Herrera, F. and Martinez, L. (2000). An approach for combining linguistic and numerical information based on 2-tuple fuzzy representation model in decision-making. *International Journal of Uncertainty, Fuzziness and Knowledge Based Systems* 8(5), 539-562.

Ho, Y. C. and Tsai C. Z. (2001). Comparing ANFIS and SEM in linear and nonlinear forecasting of new product development performance. *Expert Systems with Applications 38*, 6498‑6507

Homburg, C. and Kuehnl C. (2014). Is the more always better? A comparative study of internal and external integration practices in new product and new service development. *Journal of Business Research 67*, 1360–1367

Hwang, C.L. and Yoon K. (1981). Multiple Attribute Decision Making: Methods and Applications, Springer-Verlag, New York.

Hede, S., Nunes, M. J. L., Ferreira, P. F. V. and Rocha, L. A. (2013). Incorporating sustainability in decision-making for medical device development. *Technology in Society* 35, 276-293.

Herrera, F. and Martinez, L. (2000). A 2-tuple fuzzy linguistic representation model for computing with words. *IEEE Transactions on Fuzzy Systems*, 8(6), 746-752.

Herrera, F. and Martinez, L. (2001). A model based on linguistic 2-tuples for dealing with multigranular hierarchical linguistic contexts in multi-expert decision-making. *IEEE T. Syst. Man.Cy. B,* 31(2), 227-234.

Iranmanesh, H. and Thomson, V. (2008). Competitive advantge by adjusting design characteristics to satisfy cost targets. *International Journal of Production Economics, 115, 64-71.*

Ju, Y., Wang, A. and Liu X. (2012). Evaluating emergency response capacity by fuzzy AHP and 2-tuple fuzzy linguistic approach. *Expert Systems with Applications* 39, 6972–6981.

Juan, C. Y., Yang, O. C. and Lin, S. J. (2009). A process-oriented multi-agent system development approach to support the cooperation-activities of concurrent new product development. *Computers & Industrial Engineering* 57, 1363-1376.

Kahraman, C., Büyüközkan, G. and Ateş, Y. N. (2007). A two phase multi-attribute decision-making approach for new product introduction. *Information Sciences* 177, 1567-1582.

Karsak, E. E. and Dursun, M. (2015). An integrated fuzzy MCDM approach for supplier evaluation and selection. *Computers & Industrial Engineering* 82, 82-9.

Kettunen, J., Cockayne, Y., Degraeve, Z. and Reyck, B. (2015). New product development flexibility in a competitive environment. *European Journal of Operational Research* 244, 892-904.

Klir, G. J. and Clair, U. S. and Yuan B. (1997). Fuzzy Set Theory: Foundations and Applications. *Prentice Hall, Englewood cliffs, NJ.*

Lechler, T. and Thomas, J. (2015). Examining new product development project termination decision quality at the portfolio level: Consequences of dysfunctional executive advocacy. *International Journal of Project Management* 33, 1452-1463.

Lee, Y. and Wang, K. (2012). Performance impact of new product development processes for distinct scenarios under different supplier-manufacturer relationships. *Mathematics and Computers in Simulation* 82, 2096-2108.

Li, C., Zeng, S., Pan, T. and Zheng, L. (2014). A method based on induced aggregation operators and distance measures to multiple attribute decision-making under 2-tuple linguistic environment. Journal of Computer and System Sciences 80, 1339-1349.

Liang, B., Kale, S. H. and Cherian, J. (2014). Is the future static or dynamic? The role of culture on escalation of commitment in new product development. *Industrial Marketing Management* 43, 155-163.

Liao, S. H., Hsieh, C. L. and Huang, S. P. (2008). Mining product maps for new product development. *Expert Systems with Applications* 34, 50-62.

Liu, H. T. and Wang C. H. (2010). An advanced quality function deployment model using fuzzy analytic network process. *Applied Mathematical Modelling* 34, 3333–3351.

Lo, C. C., Wang, P. and Chao, M. K. (2006). A fuzzy group-preferences analysis method for new-product development. *Expert Systems with Applications* 31, 826-834.

Maffin, D. and Braiden, P. (2001). Manufacturing and supplier roles in product development. *International Journal of Production Economics* 69, 205–213.

Maravelias, C. T. and Grossman, I. E. (2004). Optimal resource investment and scheduling of tests for new product development. *Computers and Chemical Engineering* 28, 1021-1038.

Marmier, F., Deniaud, I. and Gourc, D. (2014). Strategic decision-making in NPD projects according to risk: Application to satellites design projects. *Computers in Industry* 65, 1107-1114.

Mazzola, E., Perrone, G. and La, Diega S. (2008). Shaping inter-firm collaboration in new product development in the automobile industry: A trade-off between a transaction and relational-based approach. *CIRP Annals - Manufacturing Technology* 57, 485-488.

Mazzola. E., Peronne. G. and Kamuriwo D. S. (2015). Network embeddedness and new product development in the biopharmaceutical industry: Themoderatingroleofopen innovation flow. *Int. J.ProductionEconomics160*, 106–119.

Mu, J. (2015). Marketing capability, organizational adaptation and new product development performance. *Industrial Marketing Management* 49, 151-166.

Ngan, C. S. (2011). Decision making with extended fuzzy linguistic computing, with applications to new product development and survey analysis. *Expert Systems with Applications* 38, 14052-14059.

Nishino, N., Lino, T., Tsuji, N., Kageyama, K. and Ueda, K (2011). Interdependent decision-making among stakeholders in electric vehicle development. *CIRP Annals - Manufacturing Technology 60,* 441–444.

Oehmen, J., Olechowski, A., Kenley, C. R. and Daya, M. B. (2014). Analysis of the effect of risk management practices on the performance of new product development programs. *Technovation* 34, 441-453.

Oh, J., Lee, S. and Yang, J. (2015). A collaboration model for new product development through the integration of PLM and SCM in the electronics industry. *Computers in Industry* 73, 82-92.

Roper, S., Micheli, P., Love, J. H. and Vahter, P. (2016). The roles and effectiveness of design in new product development: A study of Irish manufacturers. *Research Policy* 45, 319-329.

Rossi, M., Kerga, E., Taisch, M. and Terzi, S. (2014). Engineering and Design Best Practices in New Product Development: an Empirical Research. *Procedia* 21, 455-460.

Shen, C. Y. and Yu, K. Z. (2009). Enhancing the efficacy of supplier selection decision-making on the initial stage of new product development: A hybrid fuzzy approach considering the strategicand operational factors simultaneously. *Expert Systems with Applications* 36, 11271-11281.

Sjoerdsma, M. and Weele, A. (2015). Managing supplier relationships in a new product development context, *Journal of Purchasing & Supply Management* 21, 192-203.

Swink, M. and Song, M. (2007). Effects of marketing-manufacturing integration on new product development time and competitive advantage. *Journal of Operations Management* 25, 203-217.

Tang, D., Yang, B. J., Chin, S. K., Wong, Z. and Liu, X. (2011). A methodology to generate a belief rule base for customer perception risk analysis in new product development. *Expert Systems with Applications* 38, 5373-5383.

Taylan, O., Kaya, D. and Demirbas, A. (2016). An integrated multi attribute decision model for energy efficiency process in petrochemical industry applying fuzzy set theory. *Energy Conversion and Management* 117, 501-512.

Trappey, J. C. A. and Chiang, T. A. (2008). A DEA benchmarking methodology for project planning and management of new product development under decentralized profit-center business model. *Advanced Engineering Informatics* 22, 438-444.

Viedma, E. H., Herrera, F., Chiclana F. and Luque M. (2004). Some issues on consistency of fuzzy preference relations. *European Journal of Operational Research 154*,98–109

Wang, J. and Lin, I. Y. (2009). An overlapping process model to assess schedule risk for new product development. *Computers & Industrial Engineering* 57, 460-474.

Wang, W. P. (2010). A fuzzy linguistic computing approach to supplier evaluation. *Applied Mathematical Modelling,* 34, 3130-3141.

Wang, W. P. (2009). Evaluating new product development performance by fuzzy linguistic computing. *Expert Systems with Applications* 36, 9759-9766.

Xiao, Y., Zhang, H., Basadur, T. M. (2016). Does information sharing always improve team decision making? An examination of the hidden profile condition in new product development, *Journal of Business Research* 69, 587-595.

Yang, K., Zhao, R. and Lan, Y. (2014). The impact of risk attitude in new product development under dual information asymmetry. *Computers & Industrial Engineering* 76 , 122-137.

Yeh, T. M., Pai, F. Y. and Liao, C. W. (2014). Using a hybrid MCDM methodology to identify critical factors in new product development. *Neural Computing and Applications 24,* 957-971.

You, X. Y., You, J. X., Liu, H. C. and Zhen, L. (2015). Group Multi-criteria supplier selection using an extended VIKOR method with interval 2-tuple linguistic information. *Expert Systems with Applications* 42, 1906–1916.

Yuen, K. K. F. (2014). A hybrid fuzzy quality function deployment framework using cognitive network process and aggregative grading clustering: An application to cloud software product development. *Neurocomputing 142*, 95–106.

Zadeh, L. A. (1965). Fuzzy Sets. *Information and Control 8,* 338-353.

Zapatero, C. G., Benito, J.G. and Lannelongue G. (2016). Antecedents of functional integration during new product development: The purchasing–marketing link. *Industrial Marketing Management 52*, 47–59

Zhao, Y., Cavusgil, E. and Cavusgil S. (2014). An investigation of the black-box supplier integration in new product development. *Journal of Business Research 67,* 1058-1064.

BIOGRAPHICAL SKETCH

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She is the co-author of the paper entitled "A Fuzzy MCDM Approach to Determine Critical Evaluation Criteria in Washing Liquid Material Selection Procedure" which will be presented in World Congress on Engineering (WCE 2016).

PUBLICATIONS

- Dursun, M. and Arslan, O. (2016). A Fuzzy MCDM Approach to Determine Critical Evaluation Criteria in Washing Liquid Material Selection Procedure.