Niğde Ömer Halisdemir Üniversitesi Mühendislik Bilimleri Dergisi
Nigde Omer Halisdemir University Journal of Engineering Sciences
ISSN: 2564-6605
Araştırma / Research

DETERMINING DESIGN ATTRIBUTES OF A SMALL HOUSEHOLD APPLIANCE USING FUZZY VIKOR-BASED QFD METHOD

G.Nilay YÜCENUR[1,*], Gökhan ALTUN[2], Mehmet ERDEM[3]

[1]Beykent University, Industrial Engineering Department, İstanbul, Turkey

ABSTRACT

Due to globalization, competition for firms is growing with the growth of markets. Quality Function Deployment (QFD) is a systematic approach which is developed in order to pre-plan the product specifications, process specifications and production stages in the design phase in order to reflect the customer's requests and expectations to the product. This study is concerned with the design of a pomegranate extractor that can be easily used in homes and workplaces according to the desired customer demands. The fuzzy VIKOR method was used to increase the reliability of subjective judgments in the QFD, for determining the relative importance weights of customer needs "WHATs" and ranking design attributes "HOWs". The solution obtained by fuzzy logic is compared with the solutions obtained by the classical QFD and the small home appliance is designed visually by presenting the evaluations.

Keywords: Customer needs, Fuzzy logic, Multi criteria decision making, QFD, Design

BULANIK VIKOR TEMELLİ KFG YÖNTEMİ KULLANARAK KÜÇÜK BİR EV ALETİNİN TASARIM ÖZELLİKLERİNİN BELİRLENMESİ

ÖZET

Günümüzde küreselleşme olgusuyla birlikte büyüyen pazarlar şirketler arasındaki rekabetin de artmasına neden olmaktadır. Bu aşamada, Kalite Fonksiyonu Göçerimi (KFG) yöntemi, müşterinin istek ve beklentilerini ürüne yansıtmak için tasarım aşamalarındaki ürün şartnamelerini, proses şartnamelerini ve üretim aşamalarını önceden planlamak için geliştirilen sistematik bir yaklaşımdır. Bu çalışma, istenen müşteri taleplerine göre evlerde ve işyerlerinde rahatlıkla kullanılabilecek bir nar ekstraktörünün tasarımı ile ilgilidir. Bulanık VIKOR metodu, kalite fonksiyonu göçerimi yöntemindeki öznel yargıların güvenilirliğini artırmak amacıyla müşteri ihtiyaçlarının "NELER" ve tasarım özelliklerinin "NASILLAR" sıralamasının gerçekleştirilmesi için kullanılmıştır. Bulanık mantık ile elde edilen çözüm, klasik KFG tarafından elde edilen çözümlerle karşılaştırılmış ve elde edilen verilere göre küçük ev aletinin tasarımı gerçekleştirilerek görsel olarak sunulmuştur.

Anahtar kelimeler: Müşteri ihtiyaçları, Bulanık mantık, Çok kriterli karar verme, KFG, Tasarım

1. INTRODUCTION

In today's markets where competition is increasing due to globalization, companies have to be constantly innovating in order to be able to withstand competition and have to make customer-focused production knowing their needs and requirements. Product design is a matter to be meticulously focused on. Because customers' perception about the cost of production, the production method, the selling price of the product, the profit of the company, the materials used in production are formed the basis during the design of the product [1].

Today's customers know what they want, express their needs and choose products that satisfy their feelings and needs in terms of technical design and price. For this reason, it is very important to understand which product features are meaningful to the customer and to reflect the feedback from the customers to the design and development process of the product. Quality function deployment (QFD), which is used during product design phase, is a way of securing design quality of the product while the product is in the design phase. The goal of the QFD methodology is to define all technical specifications of the product or service and to identify the value of these technical specifications must have in order to fully meet customer needs.

* Sorumlu yazar / Corresponding author, e-posta / e-mail: nilayyucenur@beykent.edu.tr
Geliş / Recieved: 20.05.2019 Kabul / Accepted: 13.01.2020 doi: 10.28948/ngumuh.567969

After the introducing QFD method towards the end of the 1960s by Professor Yoji Akao in Japan lots of studies have been in the literature about this method which allows customer requests to be reflected as products' technical characteristics.

With the QFD which started to take place in the literature from the beginning of 1970's, a lot of work has been done daily from the past. Some of these studies are related to the design of new products and services. Moldovan [2] applied QFD for designing a new product in a mineral water company, Ionica and Leba [3] used the same method for a new product designing about a biometric identification system for emergency cases. Chowdhury and Quaddus [4] used QFD method for sustainable service design, Lager [5] applied QFD for designing platform-based design of non-assembled products and Yang et al. [6] used QFD for the risk management of hazardous material transportation process.

In a competitive market, QFD method that helps to provide customers with faster and more accurate products has started to be used with different decision support systems in recent years and multi-criteria decision making methods have been integrated into the QFD method. For example, Ho, He and Lee [7] used analytic hierarchy process (AHP) and QFD in strategic logistic outsourcing, Rajesh and Malliga [8] used same methods in supplier selection problem and Pakizehkar et al. [9] solved the prioritizing the bank's subtractions problem with QFD and AHP. On the other hand, Lam and Lai [10] used analytic network process (ANP) and QFD for developing environmental sustainability, Lam [11] designed a sustainable maritime supply chain with same methods and Asadabadi [12] combined ANP, QFD and Markov chain for designing a customer based supplier selection process. Also, Li et al. [13] combined TOPSIS with QFD for knowledge management system selection from the user's perspective and Akbaşa and Bilgen [14] used same methods for choosing the ideal gas fuel at WWTPs. Azadi and Saen [15] applied data envelopment analysis (DEA) and QFD to their problem and Karsak and Dursun [16] used the same methods for a supplier selection problem.

VIKOR is one of the decision-making methods which are very popular in recent years. The method focuses on the selection of the most appropriate alternative by listing alternatives under contradictory criteria and when it making this selection it use linguistic expressions which involves uncertain or not clear information for solution. Examples of integrating the fuzzy VIKOR method, which provides rational and systematic processes for finding the best solution and conciliatory solution, into the QFD can be found in the literature. For example, Cavallini et al. [17] used integral aided method for material selection based on quality function deployment and comprehensive VIKOR algorithm, in their paper C-VIKOR algorithm helped to operate and sort the final selection of alternatives. Tiwari et al. [18] evaluated product design concept by using rough sets and VIKOR method, the proposed work presented a novel modified rough VIKOR methodology for evaluating design attributes. Li and Song [19] used a rough VIKOR based QFD for prioritizing design attributes of product-related service, in this paper product attributes' importance was calculated and prioritized by the proposed rough VIKOR. Tadic et al. [20] applied the combined QFD-VIKOR method in locating city logistics terminal; they used VIKOR method for the evaluation of potential locations and selection of the best one in terms of considered criteria. Wu et al. [21] used the hesitant fuzzy DEMATEL for analyzing the interrelationships among customer requirements and determining their weights, and used the hesitant fuzzy VIKOR for prioritizing engineering characteristics in an electric vehicle. Giorgetti et al. [22] used a mixed C-VIKOR approach integrated with QFD for a material selection problem, C-VIKOR algorithm was used to technically ranking the candidate materials in their paper.

In this study, QFD method, which helps product designer and producer from beginning of the product design to production, has been combined with fuzzy VIKOR and with this solution alternative, a more realistic solution structure has been proposed than other studies in literature. Unlike previous studies, the fuzzy VIKOR method has been used both to *determine the weight of customer needs* and to *rank design features* that will meet customer needs and also for a first time in literature the house of quality has been structured with linguistic expressions of the VIKOR method. For achieving the main contribution of this paper, the customer needs of the design of a small household appliance and the design attributes of the product to meet these needs have been proposed and the house of quality has been built. Compared to the existing studies in the literature, the house of quality has been built by linguistic expressions were formed and necessary evaluations have been made with the fuzzy VIKOR method.

When the literature is examined, there are two papers about designing pomegranate extractor. One of them is Immanvel et al. [23]'s and the other one is Thakur et al. [24]'s. Both of these papers used other designing techniques instead of QFD and VIKOR.

Multi criteria decision making (MCDM) methods are used widely as a decision making method. Lots of researchers use these techniques such as AHP, ANP, VIKOR, and DEA for selecting or ranking the alternatives. For this reason, studies about house hold appliances designing are almost non-existent in the literature.

In this paper, the following two questions have been answered:

For a small home appliance that will be designed to extract pomegranate grains without damage

- What are the customer needs?
- What are the design attributes that will meet these customer needs, and in what order should they be considered?

The paper is about the design of a pomegranate extractor with QFD based on the fuzzy VIKOR method according to the desired customer demands. This paper differs from the literature with its problem type and solution techniques. Because, VIKOR and QFD methods has not previously been combined in the solution of a small household appliance design problem.

On the hand, in the literature there isn't any model like proposed in this paper that contains customer needs and design attributes.

As an outline, in Section 2 QFD method used in product design and development of the current product and what the house of quality is and how it is created are mentioned. The proposed method which is combined QFD and fuzzy VIKOR in Chapter 3 and the steps of proposed method is examined in detail. Section 4 is the case study. For designing a small household appliance which is used for extracting the pomegranate grains without damage, customer needs and design attributes are determined. In the same section, evaluation and design team are formed and customer needs are identified. With fuzzy numbers the relative importance of customer needs is determined, design attributes are identified, the correlation scores between customer needs and design attributes are determined with fuzzy numbers, finally design attributes are ranked by fuzzy VIKOR and product is designed. Modified house of quality which is formed by linguistic variables is represented in same section. The obtained results with proposed method, conclusion remarks, the limitations of our study and the suggestions for future researches are explained in conclusion part.

2. QFD AND THE HOUSE OF QUALITY

What is desired to be done with QFD is to convert customer voice (WHATs) to appropriate technical characteristics (HOWs) at every step of product development and production. Generally, a complete QFD process is composed of four successive phases. They are customer requirement planning, product characteristics deployment, process and quality control and the operative instruction [25-26]. The method is started with the matrix called Quality House. The general structure of the Quality House is shown in Figure 1.

First, the technical characteristics of the design and the customer voice are defined. Customer needs can be determined through questionnaires, the past complaints, examination of relevant customer files, electronic communications and other means of communication, and other surveys and interviews. The required technical characteristics to meet customer needs should be understandable by designers and engineers. Thus, engineers and designers can convert WHATs to HOWs during the designing, production and service activities.

The roof of the Quality House shows the reciprocal relationship between each pair of technical characteristics. The weight of technical relations is represented by different symbols and these relationships help to find out how the changes in one feature of the designed product will affect other features. The roof also guides the evaluation in case of preference between these features. Thus, technical characteristics can be evaluated collectively rather than alone.

Then, the relationship matrix between customer needs and technical characteristics is developed and it is examined whether the technical characteristics respond adequately to customer requests. The absence of a strong relationship between customer needs and any of the technical characteristics will indicate that the final product will have difficulty meeting customer needs. Similarly, any technical characteristic will be considered unnecessary if it does not affect any of the customer needs.

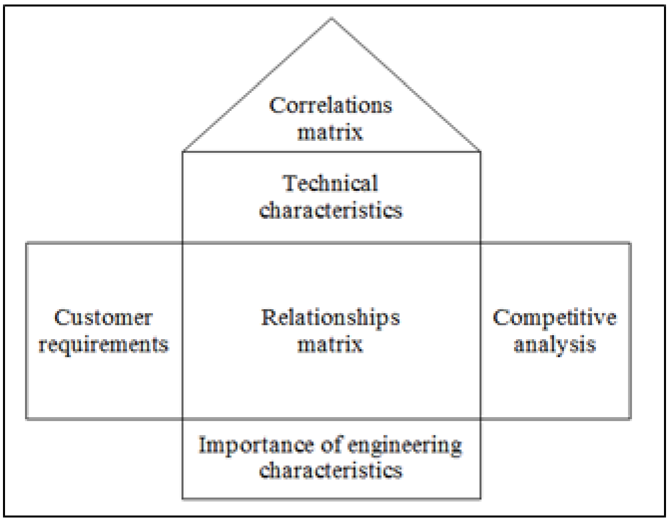


Figure 1. The general structure of the Quality House [27]

The next step in the classical Quality House is the addition of market evaluations and critical sales-points data to the evaluation matrix. This step involves sorting each customer's needs according to their importance and identifying their weaknesses and strengths relative to their competitors by evaluating their own products according to the characteristics of each customer.

At a further step of Quality House, objectives are developed by evaluating the technical characteristics of the competitor products. In order to determine the inconsistency between customer evaluations and technical evaluations, comparisons are made with in-house evaluations of how customer needs are met by competing firms. The targets are determined for each technical characteristic according to the order of customer importance and the strengths and weaknesses of the current product.

The final step of Quality House is to determine the technical characteristics that are strongly related to customer needs or that have low performance relative to competitor products. These low-performance features must be converted into product functions in the design and manufacturing process to meet customer needs. By making appropriate operations and taking precautions in this regard, customer voice can be guaranteed to be included in the design.

3. PROPOSED METHOD: QFD INTEGRATED WITH FUZZY VIKOR

One of the key features of QFD that distinguishes it from other traditional methods is that it takes into account customer needs since the product concept was introduced. Thus, the problems that arise after the product are produced and presented to the market are reduced, saving both time and cost.

In our proposed method, the fuzzy VIKOR method is used to evaluate and rank the design attributes that will meet customer needs. A new product design will be realized according to the design attributes listed by this method.

Fuzzy logic has been used in extensive applications in recent years in literature [28-29]. Fuzzy set theory which is a mathematical theory that is designed to model the vagueness or imprecision of human cognitive processes was first introduced by Zadeh in 1965 [30]. It is a branch that is based on thinking like human beings and transforms them into mathematical functions. The most important feature of the fuzzy logic is the mathematical discipline based on the Fuzzy set theory instead of the dual Aristotelian logic. With fuzzy logic, approximate values are used instead of exact values and subjective judgments are quantified by converting judgments into numbers. A fuzzy set is generally defined by a membership function that maps elements to degrees of membership within a certain interval, which is usually [0, 1] [31]. Triangular and trapezoidal fuzzy numbers are used to identify fuzzy number clusters. They are two restrict fuzzy sets with convexity and normalization, and are widely applied to modeling fuzzy data in [0, 1] interval [32].

VIKOR method is developed for multi-criteria optimization of complex systems by Opricovic and Tzeng in 2004 [33].The method focuses on making a choice between alternatives in the case of contradictory criteria and ranking these alternatives. VIKOR method determines a solution that is close to the ideal, a compromise solution that provides maximum "group benefit" and minimum "individual regret" for the majority. When it is assumed that the alternatives are evaluated according to each criterion, the compromise order is realized by comparing the approximation of the ideal solution.

In this study, the best method that can be used to implement the fuzzy VIKOR method is Sanayei, Mousavi and Yazdankhah [34]'s study. In their paper, compromise solution which provided rational, easily, systematic process was presented by following the level of optimism. The authors' process steps were adapted to the solution approach we proposed. The steps of the proposed method for solving the problem of ordering of design attributes to meet customer needs can be described by the fuzzy VIKOR method as follows:

- *Step 1:* Identifying evaluation and design team: The team that will carry out analyzes and assessments in the QFD study are identified. The team consists of engineers and designers in the company.
- *Step 2:* Identifying customer needs "WHATs": The customer needs are determined by means of survey studies, past complaints, market research and similar data collection methods.
- *Step 3:* Determining the relative importance of WHATs with fuzzy numbers: The relative importance of the customer needs determined with the data collection processes are determined by the fuzzy VIKOR method relative to each other. The expert evaluations of the fuzzy VIKOR method are carried out through evaluation questionnaires to the main customer groups related to the subject. The linguistic expressions given in Table 1 and the corresponding fuzzy numbers are used in determining the relative importance of customer needs.

Table 1. Linguistic variables and fuzzy numbers [34]

Linguistic variables for importance weight of each criterion			Linguistic variables for ratings		
Linguistic variables		**Fuzzy numbers**	**Linguistic variables**		**Fuzzy numbers**
Very low	VL	(0.0 – 0.1 – 0.2)	Very poor	VP	(0.0 – 0.1 – 0.2)
Low	L	(0.1 – 0.2 – 0.3)	Poor	P	(0.1 – 0.2 – 0.3)
Medium low	ML	(0.2 – 0.3 – 0.4 – 0.5)	Medium poor	MP	(0.2 – 0.3 – 0.4 – 0.5)
Medium	M	(0.4 – 0.5 – 0.6)	Fair	F	(0.4 – 0.5 – 0.6)
Medium high	MH	(0.5 – 0.6 – 0.7 – 0.8)	Medium good	MG	(0.5 – 0.6 – 0.7 – 0.8)
High	H	(0.7 – 0.8 – 0.9)	Good	G	(0.7 – 0.8 – 0.9)
Very high	VH	(0.8 – 0.9 – 1.0)	Very good	VG	(0.8 – 0.9 – 1.0)

Decision makers make weighting of all the importance degree of customer needs with linguistic variables which are seen in Table 1. The linguistic variables are represented by fuzzy numbers such as $\tilde{w}_{jk}$. Where, j is the number of customer need and k is the number of decision maker $(j = 1, 2, \ldots, n)$.

After decision makers' linguistic evaluations are received for each customer needs, the aggregated fuzzy weights $(\widetilde{w_j})$ of these requirements are obtained as follows:

$$\widetilde{w_j} = (w_{j1}, w_{j2}, w_{j3}, w_{j4}) \tag{1}$$

where

$$w_{j1} = min\{w_{jk1}\}_k,\ w_{j2} = \frac{1}{K}\sum_{k=1}^{K} w_{jk2},\ w_{j3} = \frac{1}{K}\sum_{k=1}^{K} w_{jk3},\ w_{j4} = max\{w_{jk4}\}_k.$$

- *Step 4:* Determining crisp numbers for WHATs: After obtaining the relative importance by means of fuzzy numbers, the crisp importance ratings of the customer needs are determined. Defuzzification of fuzzy weights of each customer needs into crisp values (w_j) is done by using center of area defuzzification method.

$$w_j = (w_{j1} + w_{j2} + w_{j3} + w_{j4})/4 \tag{2}$$

- *Step 5:* Identifying design attributes "HOWs": The design team that is created determines the features that must be found in the product in accordance with customer needs.
- *Step 6:* Determining HOWs – WHATs correlation scores with fuzzy numbers: The correlation score is calculated with fuzzy numbers to show the degree of correlation between the customer needs and the design attributes which determine to meet these requirements.

Decision makers make rating to all design attributes belonging to the customer needs with linguistic variables which are seen in Table 1. This time, the linguistic variables are represented by fuzzy numbers such as $\tilde{x}_{ijk}$. Where, i is the number of design attribute, j is the number of customer need and k is the number of decision maker $(i = 1, 2, \ldots, m$ and $j = 1, 2, \ldots, n)$.

$\tilde{x}_{ij}$ is the fuzzy rating of decision makers. This rating is made with linguistic variables about the extent to which each design attribute meets customer needs are obtained as follows:

$$\tilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4}) \tag{3}$$

where

$$x_{ij1} = min\{x_{ijk1}\}_k,\ x_{ij2} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk2},\ x_{ij3} = \frac{1}{K}\sum_{k=1}^{K} x_{ijk3},\ x_{ij4} = max\{x_{ijk4}\}_k.$$

The problem of determining which of the evaluated design attributes are more important to meet customer needs can be briefly expressed in the matrix format as follow:

$$\tilde{D} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \vdots & \vdots \\ \tilde{x}_{m1} & \tilde{x}_{m2} & \cdots & \tilde{x}_{mn} \end{bmatrix}, \tilde{W} = [\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n]$$

where $\tilde{x}_{ij}$ the rating of design attribute DA_i with respect to customer need CN_j, $\tilde{w}_j$ the importance weight of the *jth* customer need holds, and $\tilde{x}_{ij} = (x_{ij1}, x_{ij2}, x_{ij3}, x_{ij4})$ and $\widetilde{w_j} = (w_{j1}, w_{j2}, w_{j3}, w_{j4})$ are linguistic variables can be approximated by positive trapezoidal fuzzy numbers.

- *Step 7:* Determining crisp numbers for HOWs – WHATs correlation scores: After obtaining the correlation scores of customer needs and design attributes with fuzzy numbers, the crisp correlation scores are determined. Defuzzification of each design feature to the crisp numbers of the fuzzy ratings that meet the needs of the customer is done using center of area defuzzification method.

- *Step 8:* Determining the positive and negative ideal solutions: With fuzzy VIKOR method the best (f_j^*) and the worst (f_j^-) values are obtained for the customer needs from the evaluation of correlation matrix formed by the customer needs and the design attributes which meet these requirements.

$$f_j^* = \max_i x_{ij} \tag{4}$$

$$f_j^- = \min_i x_{ij} \tag{5}$$

- *Step 9:* Determining *S*, *R* and *Q* values: After calculating the best and worst values for each customer need, the S_i and R_i values are calculated for each design attribute. S value is the mean group value and R value is the worst group value. After the S_i and R_i values have been determined for each design attribute, the Q_i value indicating the maximum group benefit is obtained.

$$S_i = \sum_{j=1}^{n} w_j\left(f_j^* - f_{ij}\right)/\left(f_i^* - f_i^-\right) \tag{6}$$

$$R_i = \max_j w_j\left(f_j^* - f_{ij}\right)/\left(f_i^* - f_i^-\right) \tag{7}$$

$$Q_i = [v(S_i - S^*)/(S^- - S^*)] + [(1-v)(R_i - R^*)/(R^- - R^*)] \tag{8}$$

- *Step 10:* Ranking design attributes "HOWs": All the design attributes evaluated to meet customer needs according to *Q* value obtained are ranked. The design attribute with the lowest *Q* value is determined as the feature to be considered and formed first.
- *Step 11:* Designing new product: The new product is designed by considering the design attributes determined and evaluated to meet customer needs.

4. CASE STUDY FOR A SMALL HOUSEHOLD APPLIANCE

In this paper, we want to design a small home appliance that can be used for dividing the pieces of pomegranate which is a winter fruit. The proposed method blended with the fuzzy VIKOR in the solution phase of the work is used in the QFD philosophy with the above described process steps.

In the survey, first of all, decision makers were asked about the attributes they wanted from this small household appliance and then they were asked to evaluate the technical features that would meet these characteristics.

4.1 Identifying evaluation and design team

Our evaluation team consist 3 engineers and 3 designers from a company serving in the small household appliance industry in Turkey.

4.2 Identifying customer needs "WHATs"

After identifying evaluation and design team, the customer needs to a small home appliance that can be used for dividing the pieces of pomegranate are determined by questionnaires. After analyzing the questionnaires made, the needs of the customers for the small home appliance which will be designed for dividing the pomegranate into pieces are collected under 8 main headings. These customer needs can be listed as follows:

- *CN_1 - Robustness*: Customers want the small household appliance to be designed to be robust and long lasting.
- *CN_2 - Ease of use:* Customers want small home appliance that can be designed to be effortless and easily used.
- *CN_3 - Reasonable price:* Customers want the small home appliance to be designed to be sold with reasonably priced.
- *CN_4 - Whole pieces extraction:* The customer wants while the small home appliance that is to be designed is in use, the pieces of pomegranate to be removed without being spoiling and crushed.
- *CN_5 - Lightness:* Customers want the small home appliance to be designed to be lightweight.
- *CN_6 - Low energy consumption:* Customers want the small household appliance to be designed to have low energy consumption and not cause a significant increase in electricity consumption.
- *CN_7 - Ergonomic structure:* Customers want to the small household appliances to be designed ergonomically, to be suitable with anthropometric features in terms of grip and use.
- *CN_8 - Small volume:* Customers want small household appliances to be designed in small volume and not to take up too much space on the counter.

4.3 Determining the relative importance of WHATs with fuzzy numbers

The relative importance of the customer needs is determined by three different customer groups with questionnaires with linguistic variables given in Table 1. The first customer group consists of 25-50 year old housewife, the second customer group consists of 25-50 year old working ladies and the 25-50 year old men are in the third customer group. The linguistic variables are converted to fuzzy numbers. The determination of weights of customer needs can be seen in Table 2.

Table 2. Determination of weights of customer needs

	Customer group 1	**Customer group 2**	**Customer group 3**
CN_1 Robustness	H (0.7 – 0.8 – 0.9)	VH (0.8 – 0.9 – 1.0)	MH (0.5 – 0.6 – 0.7 – 0.8)
CN_2 Ease of use	H (0.7 – 0.8 – 0.9)	MH (0.5 – 0.6 – 0.7 – 0.8)	H (0.7 – 0.8 – 0.9)
CN_3 Reasonable price	VH (0.8 – 0.9 – 1.0)	MH (0.5 – 0.6 – 0.7 – 0.8)	VH (0.8 – 0.9 – 1.0)
CN_4 Whole pieces extraction	VH (0.8 – 0.9 – 1.0)	VH (0.8 – 0.9 – 1.0)	VH (0.8 – 0.9 – 1.0)
CN_5 Lightness	M (0.4 – 0.5 – 0.6)	ML (0.2 – 0.3 – 0.4 – 0.5)	ML (0.2 – 0.3 – 0.4 – 0.5)
CN_6 Low energy consumption	L (0.1 – 0.2 – 0.3)	ML (0.2 – 0.3 – 0.4 – 0.5)	L (0.1 – 0.2 – 0.3)
CN_7 Ergonomic structure	M (0.4 – 0.5 – 0.6)	MH (0.5 – 0.6 – 0.7 – 0.8)	L (0.1 – 0.2 – 0.3)
CN_8 Small volume	H (0.7 – 0.8 – 0.9)	MH (0.5 – 0.6 – 0.7 – 0.8)	VH (0.8 – 0.9 – 1.0)

4.4 Determining crisp numbers for WHATs

After obtaining the relative importance by means of fuzzy numbers, the crisp importance ratings of the customer needs are determined. Defuzzification is done by using center of area defuzzification method with Equation 2.

The weights of customer requirements according to Table 2 and Equation 2 are found as follows:

$w_1 = [(0.50 + 0.77 + 0.80 + 1.00) / 4] = 0.77$
$w_2 = [(0.50 + 0.73 + 0.77 + 0.90) / 4] = 0.73$
$w_3 = [(0.50 + 0.80 + 0.83 + 1.00) / 4] = 0.78$
$w_4 = [(0.80 + 0.90 + 0.90 + 1.00) / 4] = 0.90$
$w_5 = [(0.20 + 0.37 + 0.43 + 0.60) / 4] = 0.40$
$w_6 = [(0.10 + 0.23 + 0.27 + 0.50) / 4] = 0.28$
$w_7 = [(0.10 + 0.43 + 0.47 + 0.80) / 4] = 0.45$
$w_8 = [(0.50 + 0.77 + 0.80 + 1.00) / 4] = 0.77.$

According to these values, in the light of the questionnaire survey, the customers want to have the small household appliances which can be extracted without breaking the pieces of pomegranate as a whole. However, the small size, robustness and affordability of the small household appliance to be designed are other features that customers consider important. The crisp importance ratings of the customer needs are shown in Table 3.

Table 3. The crisp importance ratings of the customer needs

	CN_1	CN_2	CN_3	CN_4	CN_5	CN_6	CN_7	CN_8
Weights	0.77	0.73	0.78	0.90	0.40	0.28	0.45	0.77

4.5 Identifying design attributes "HOWs"

The created design team determines the features that must be included in the product according to the needs of the customer. The number of suggestions suggested by the team is limited to opinion surveys and the 5 most important design attributes that respond to customer requests are considered. These specifications can be listed as follows:

- *DA_1 - Plastic stainless material*: Plastic material is suitable to meet the needs such as lightness, robustness, easy cleaning and reasonable price of the product to be designed.
- *DA_2 - Receptacle without stain:* The pomegranate stain is quite dense and very difficult to remove from the infected object. For this reason, it is important that the product receptacle should be made of stain proof material so that it can be easily cleaned and preserved like the first day.
- *DA_3 - Impact balls:* The product to be designed should ensure that the pomegranate grains can be extracted without breaking down and being crushed. For this reason, there should be small balls in the product that will create a blow effect that will divide the pomegranate grains from the fruit.

- *DA_4 - Ergonomic design:* Ergonomic design: It is very important that the product to be designed should be easy to use for its users, and it should conform to the anthropometric properties of its users.
- *DA_5 - Small size and light weight material:* It is requested that the product to be designed is in small size. It is enough that the product is in a size that can extract a pomegranate, it is important that it does not take up much space and is made of light material.

4.6 Determining HOWs – WHATs correlation scores with fuzzy numbers

Once the customer needs and the suggested design attributes to meet these needs have been identified, the relationships between these components are defined. The degree to which each design attribute meets the each customer need is evaluated according to the linguistic variables in Table 1 with the help of the fuzzy VIKOR method. The evaluations made according to decision maker opinions can be seen in Table 4.

Table 4. Evaluation of design attributes according to customer needs by decision makers

		CN_1	CN_2	CN_3	CN_4	CN_5	CN_6	CN_7	CN_8
Decision maker 1	Plastic stainless material	VG	MG	MG	F	VG	MG	MP	MP
	Receptacle without stain	MP	P	VP	P	P	VP	MP	VP
	Impact balls	VP	F	P	VG	VP	VP	F	MP
	Ergonomic design	MP	VG	MP	G	MG	P	VG	F
	Small size - lightweight material	P	MG	MG	P	MG	MG	MG	VG
Decision maker 2	Plastic stainless material	VG	MP	F	MP	VG	F	MP	MP
	Receptacle without stain	P	P	VP	VP	VP	VP	P	MP
	Impact balls	VP	MG	P	VG	P	VP	MP	P
	Ergonomic design	P	VG	MP	MG	MP	VP	VG	F
	Small size - lightweight material	P	F	G	MP	VG	F	F	VG
Decision maker 3	Plastic stainless material	VG	F	F	MP	MG	F	MG	F
	Receptacle without stain	F	MP	VP	MP	P	VP	P	VP
	Impact balls	VP	F	P	VG	P	VP	F	P
	Ergonomic design	F	MG	VP	MP	MP	MP	MG	MG
	Small size - lightweight material	P	F	G	VP	VG	F	F	VG

4.7 Determining crisp numbers for HOWs – WHATs correlation scores

For the determination by the linguistic variables of each design attribute that satisfy customer needs the fuzzy numbers corresponding to these linguistic variables are used. After this evaluation for each design attribute, the corresponding customer satisfaction level is obtained in a fuzzy manner. These obtained fuzzy evaluations need to be translated into crisp numbers. Defuzzification is done by using center of area defuzzification method and the results can be seen Table 5.

Table 5. Crisp numbers for the degree which each design attribute meet customer needs

	CN_1	CN_2	CN_3	CN_4	CN_5	CN_6	CN_7	CN_8
Weights	0.77	0.73	0.78	0.90	0.40	0.28	0.45	0.77
Plastic stainless material	0.90	0.50	0.58	0.40	0.78	0.58	0.48	0.40
Receptacle without stain	0.35	0.28	0.10	0.23	0.16	0.10	0.28	0.22
Impact balls	0.10	0.58	0.20	0.90	0.16	0.10	0.43	0.28
Ergonomic design	0.35	0.78	0.26	0.58	0.48	0.23	0.78	0.58
Small size - lightweight material	0.20	0.58	0.73	0.23	0.78	0.58	0.58	0.90

Calculation example of crisp value for CN1 about plastic stainless material attributes: According to Table 4 all decision makers expressed that this attribute meets to CN1 with Very Good (it means (0.8 – 0.9 – 1.0) according to Table 1). The average of these values is 0.9. For all technical attribute these crisp values were calculated.

4.8 Determining the positive and negative ideal solutions

The best (f^*) and worst (f^-) values are obtained with Eq. (4) and Eq. (5) from the correlation matrix occurred with the evaluation of each design attribute which meets each customer need. Table 6 shows the results of these values for each customer need.

Table 6. Best and worst values for each customer need

	CN_1	CN_2	CN_3	CN_4	CN_5	CN_6	CN_7	CN_8
f^*	0.90	0.78	0.73	0.90	0.78	0.58	0.78	0.90
f^-	0.10	0.28	0.10	0.23	0.16	0.10	0.28	0.22

4.9 Determining S, R and Q values

After calculating the best and worst values for each customer need, the *S*, *R* and *Q* values are calculated for each design attribute with Eq. (6), Eq. (7) and Eq. (8). The results can be seen in Table 7.

Table 7. *S*, *R* and *Q* values for all design attributes

	DA_1	DA_2	DA_3	DA_4	DA_5
S	2.10	4.84	3.42	2.30	2.05
R	0.67	0.90	0.77	0.58	0.90
Q	0.15	1.00	0.54	0.05	0.50

4.10 Ranking design attributes "HOWs"

All design attributes evaluated to meet customer needs are ranked according to the Q value obtained. According to the ranking values shown in Table 8, the fact that the small household appliance to be designed for extract the pomegranate's grains has an ergonomic design is a primary attribute to be considered and formed. The product which is designed after ergonomic design attributes needs to be made with small size and light weight from plastic stainless material.

Table 8. S, R, Q values and the ranking of design attributes according to these values

Plastic stainless Material	Receptacle without Stain	Impact balls	Ergonomic design	Small size and light weight material
2	5	4	**1**	3

After all calculations, with VIKOR and QFD method the design attributes were ranked. According to this ranking ergonomic design is the most important attribute for this new small household appliance that should be. After this attribute, plastic stainless material and using material with small size and light weight are other important design attributes.

4.11 Designing new product

With the research and evaluation work done in this paper, the main design features of the small household appliance which extract pomegranate grains have been determined according to customer requests. Accordingly, the product to be designed will be designed with small size and ergonomic from stainless plastic material. An example of proposed product drawing for researchers and manufacturers is shown in Figure 2.

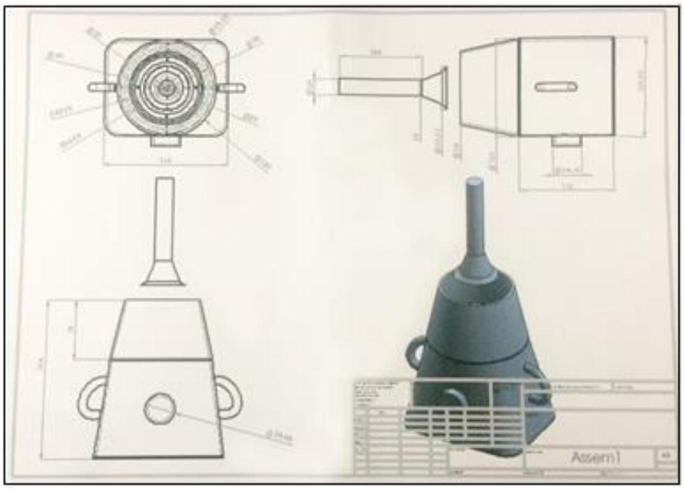


Figure 2. Proposed product drawing

In the proposed product design, the pomegranate fruit which is placed in the bowl made of stainless plastic material will be separated from the natural separation parts by the pressure force to be applied from above.

The sharp knives placed on the recommended product, corresponding to the natural separation divisions of the pomegranate, will cut the husk without entering the pod so that the pomegranate grains will not be damaged.

4.12 Modification of Classical House of Quality

One of the main features that distinguish QFD from other traditional methods is the consideration of customer needs since the product was introduced. Thus, the problems that arise after the product is produced and presented to the market are reduced, saving both time and cost. The aim of QFD is to transform the customer requests to the appropriate technical attributes at every stage of product development and production.

The evaluations which are given in Table 2 and Table 4 for the problem of sorting the design features of the small household appliance which will be designed to be able to remove the pomegranate grains in the scope of the study are transferred to the house of quality structure and the modified house of quality is shown in Figure 3.

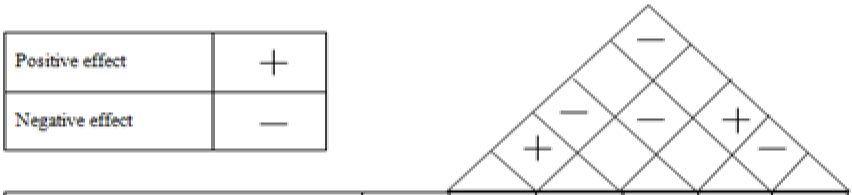
	IMPORTANCE WEIGHTS			Plastic stainless material			Receptacle without stain			Impact balls			Ergonomic design			Small size and lightweight material		
	CG_1	*CG_2*	*CG_3*	*DM_1*	*DM_2*	*DM_3*	*DM_1*	*DM_2*	*DM_3*	*DM_1*	*DM_2*	*DM_3*	*DM_1*	*DM_2*	*DM_3*	*DM_1*	*DM_2*	*DM_3*
Robustness	H	VH	MH	VG	VG	VG	MP	P	F	VP	VP	VP	MP	P	F	P	P	P
Ease of use	H	MH	H	MG	MP	F	P	P	MP	F	MG	F	VG	VG	MG	MG	F	F
Reasonable price	VH	MH	VH	MG	F	F	VP	VP	VP	P	P	P	MP	MP	VP	MG	G	G
Whole pieces extraction	VH	VH	VH	F	MP	MP	P	VP	MP	VG	VG	VG	G	MG	MP	P	MP	VP
Lighness	M	ML	ML	VG	VG	MG	P	VP	P	VP	P	P	MG	MP	MP	MG	VG	VG
Low energy consumption	L	ML	L	MG	F	F	VP	VP	VP	VP	VP	VP	P	VP	MP	MG	F	F
Ergonomic structure	M	MH	L	MP	MP	MG	MP	P	P	F	MP	F	VG	VG	MG	MG	F	F
Small volume	H	MH	VH	MP	MP	F	VP	MP	VP	MP	P	P	F	F	MG	VG	VG	VG

CG: Customer Group
DM: Decision Maker

Figure 3. Modified house of quality

In Figure 3, there are customer needs, design features that can meet these customer needs, and reciprocal relationship of design attributes to each other.

The importance weights of the customer needs and the values of the proposed design attributes that can meet the customer needs were obtained by the fuzzy VIKOR method. All these evaluations as well as the order in which the design attributes must be taken into account are shown in Figure 4.



		IMPORTANCE WEIGHTS	Plastic stainless material	Receptacle without stain	Impact balls	Ergonomic design	Small size and lightweight material
Robustness		0.77	0.90	0.35	0.10	0.35	0.20
Ease of use		0.73	0.50	0.28	0.58	0.78	0.58
Reasonable price		0.78	0.58	0.10	0.20	0.26	0.73
Whole pieces extraction		0.90	0.40	0.23	0.90	0.58	0.23
Lightness		0.40	0.78	0.16	0.16	0.48	0.78
Low energy consumption		0.28	0.58	0.10	0.10	0.23	0.58
Ergonomic structure		0.45	0.48	0.28	0.43	0.78	0.58
Small volume		0.77	0.40	0.22	0.28	0.58	0.90
VALUES		*S*	2.10	4.84	3.42	2.30	2.05
		R	0.67	0.90	0.77	0.58	0.90
		Q	0.15	1.00	0.54	0.05	0.50
RANKING			2	5	4	1	3

Figure 4. Importance weights of customer needs and the ranking of design attributes

With the proposed method firstly customer needs were ranked with their importance ratings with VIKOR method. According to these values whole pieces extraction is the most important customer need. Reasonable price, robustness, small volume, ease of use, ergonomic structure, lightness, and low energy consumption follow this need, respectively.

After the finding of the importance ratings of the customer needs, design attributes were ranked by QFD method. According to this ranking, ergonomic design is the most important design attribute to meet customer needs. Other design attributes such as plastic stainless material, small size and light weight material, impact balls, and receptacle without stain follow this attribute, respectively.

5. CONCLUSION AND FUTURE RESEARCH

In today's markets, which are increasingly competitive due to globalization, companies must constantly innovate in order to be able to withstand competition, and they need to be very aware of customer needs and requirements. For this reason, the firms need more effective methods in product development and improvement processes. QFD is the one of these effective methods used in this area.

The firms which implement QFD gain many important competitive advantages. For example, firms implementing the QFD method can develop products based on customer needs, provide more customer satisfaction, ensure that the product reaches the market in a shorter time, and compete in the market by bringing advanced product performance to the forefront.

With QFD method, the priorities of the customer needs and requirements are determined and according to the customer's voice, the product related attributes are ordered according to importance weights. Thus, when designers are forced to choose between customer needs due to technical or aesthetic reasons in product design, they are able to examine QFD's result and design the product accordingly. QFD results also reveals which technical attributes should be studied more in the design stage of the product.

In this study, customer needs were determined for a small home appliance that would be designed to be able to remove pomegranate grains without any damage, and the importance ratings of these customer needs were calculated differently from other studies in literature by using the fuzzy VIKOR method. After determining the importance ratings of the customer needs in the study, the design attributes recommended to meet these needs were evaluated with the fuzzy VIKOR method. In the evaluations made by the fuzzy VIKOR method, linguistic expressions were used by translating triangular and trapezoidal numbers so that more realistic expression of subjective judgments was added to the calculations.

The most important limitation of our work is to reach a limited number of customers for the small home appliance to be designed and to not be able to determine the customer needs of sufficient width. At this point, in further studies more customers can be reached with much more extensive survey work. With these field studies, more customer needs and design attributes that meet these customer needs can be identified and a larger house of quality can be created with all this information. The calculations required for this larger house of quality can also be done with the method proposed in this study.

The fuzzy VIKOR method proposed in this study is a structure that can be easily applied to any kind of sector product in terms of helping to design new product and improvement of existing product attributes because of ease of use. For this reason, this paper is a guideline for future work with the proposed solution method.

REFERENCES

[1] Y. Z. Chen, and E. W. T. Ngai, "A fuzzy QFD program modelling approach using the method of imprecision", International Journal of Production Research, vol. 46, no. 24, pp. 6823-6840, 2008.

[2] L. Moldovan, "QFD employment for a new product design in a mineral water company", Procedia Technology, vol. 12, pp. 462-468, 2014.

[3] A. C. Ionica, and M. Leba, "QFD integrated in new product development - biometric identification system case study", Procedia Economics and Finance, vol. 23, pp. 986-991, 2015.

[4] Md. M. H. Chowdhury, and M. A. Quaddus, "A multi-phased QFD based optimization approach to sustainable service design", International Journal of Production Economics, vol. 171, no. 2, pp. 165-178, 2016.

[5] T. Lager, "A conceptual framework for platform-based design of non-assembled products", Technovation, vol. 68, pp. 20-34, 2017.

[6] Q. Yang, K. S. Chin, and Y. L. Li, "A quality function deployment-based framework for the risk management of hazardous material transportation process", Journal of Loss Prevention in the Process -Industries, vol. 52, pp. 81-92, 2018.

[7] W. Ho, T. He, C. K. M. Lee, and A. Emrouznejad, "Strategic logistics outsourcing. Expert Systems with Applications", vol. 39, no. 12, pp. 10841-10850, 2012.

[8] G. Rajesh, and P. Malliga, "Supplier selection based on AHP-QFD methodology", Procedia Engineering, vol. 64, pp. 1283-1292, 2013.

[9] H. Pakizehkar, M. M. Sadrabadi, R. Z. Mehrjardi, and A. E. Eshaghieh, "The application of integration of Kano's Model, AHP technique and QFD matrix in prioritizing the bank's substructions", Procedia - Social and Behavioral Sciences, vol. 230, pp. 159-166, 2016.

[10] J. S. L. Lam, and K. H. Lai, "Developing environmental sustainability by ANP-QFD approach: the case of shipping operations", Journal of Cleaner Production, vol. 105, pp. 275-284, 2015.

[11] J. S. L. Lam, "Designing a sustainable maritime supply chain: A hybrid QFD–ANP approach", Transportation Research Part E: Logistics and Transportation Review, vol. 78, pp. 70-81, 2015.

[12] M. R. Asadabadi, "A customer based supplier selection process that combines quality function deployment, the analytic network process and a Markov chain", European Journal of Operational Research, vol. 263, no. 3, pp. 1049-1062, 2017.

[13] M. Li, L. Jin, and J. Wang, "A new MCDM method combining QFD with TOPSIS for knowledge management system selection from the user's perspective in intuitionistic fuzzy environment", Applied Soft Computing, vol. 21, pp. 28-37, 2014.

[14] H. Akbaş, and B. Bilgen, "An integrated fuzzy QFD and TOPSIS methodology for choosing the ideal gas fuel at WWTPs", Energy, vol. 125, pp. 484-497, 2017.

[15] M. Azadi, and R. F. Saen, "A combination of QFD and imprecise DEA with enhanced Russell graph measure: A case study in healthcare", Socio-Economic Planning Sciences, vol. 47, no. 4, pp. 281-291, 2013.

[16] E. Karsak, and M. Dursun, "An integrated supplier selection methodology incorporating QFD and DEA with imprecise data", Expert Systems with Applications, vol. 41, no. 16, pp. 6995-7004, 2014.

[17] C. Cavallini, A. Giorgetti, P. Citti, and F. Nicolaie, "Integral aided method for material selection based on quality function deployment and comprehensive VIKOR algorithm", Materials & Design, vol. 47, pp. 27-34, 2013.

[18] V. Tiwari, P. K. Jain, and P. Tandon, "Product design concept evaluation using rough sets and VIKOR method", Advanced Engineering Informatics, vol. 30, no. 1, pp. 16-25, 2016.

[19] X. Li, and W. Song, "A rough VIKOR-based QFD for prioritizing design attributes of product-related service", Mathematical Problems in Engineering Article ID 9642018, 2016.

[20] S. Tadic, S. Zezevic, and M. Krstic, "Locating city logistics terminal by applying the combined QFD-VIKOR method", Paper presented at International Conference on Traffic and Transport Engineering, Belgrade, November 24-25, 2016.
[21] S. M. Wu, H. C. Liu, and L. E. Wang, "Hesitant fuzzy integrated MCDM approach for quality function deployment: A case study in electric vehicle", International Journal of Production Research, vol. 55, no. 15, pp. 4436-4449, 2017.
[22] A. Giorgetti, C. Cavallini, G. Arcidiacono, and P. Citti, "A Mixed C-VIKOR fuzzy approach for material selection during design phase: A case study in valve seats for high performance engine", International Journal of Applied Engineering Research, vol. 12, no. 12, pp. 3117-3129, 2017.
[23] A. Immanvel, M. Manikandan, M. I. Sadiq, R. Sridhar, and K. Velmurugan, "Design and fabrication of pomegranate aril (PULP) extractor, International Journal of Innovative Research in Science, Engineering and Technology, vol. 3, no. 1, pp. 1218-1221, 2014.
[24] A. K. Thakur, R. T. Patil, D. B. Singh, and R. K. Gupta, "Development of tool and machine for safe separation of arils from pomegranate", Acta horticulturae, vol. 890, no. 890, pp. 425-432, 2011.
[25] S. Yang, J. Liu, K. Wang, and Y. Miao, "An uncertain QFD approach for the strategic management of logistics services", Mathematical Problems in Engineering, Article ID 1486189.
[26] M. Li, "The extension of Quality Function Deployment based on 2-tuple linguistic representation model for product design under multigranularity linguistic environment", Mathematical Problems in Engineering. Article ID 989284.
[27] H. T. Liu, "Product design and selection using fuzzy QFD and fuzzy MCDM approaches", Applied Mathematical Modelling, vol. 35, pp. 482–496, 2011.
[28] N. Zhang, K. Zhou, and X. Du, "Application of fuzzy logic and fuzzy AHP to mineral prospectivity mapping of porphyry and hydrothermal vein copper deposits in the Dananhu-Tousuquan island arc, Xinjiang, NW China", Journal of African Earth Sciences, vol. 128, pp. 84-96, 2017.
[29] L. Suganthi, S. Iniyan, and A. A. Samuel, "Applications of fuzzy logic in renewable energy systems – A review", Renewable and Sustainable Energy Reviews, vol. 48, pp. 585–607, 2015.
[30] S. Tadic, S. Zecevic, and M. Krstic, "A novel hybrid MCDM model based on fuzzy DEMATEL, fuzzy ANP and fuzzy VIKOR for city logistics concept selection", Expert Systems with Applications, vol. 41, pp. 8112–8128, 2014.
[31] Z. P. Tian, J. Q. Wang, J. Wang, and H. Y. Zhang, "A multi-phase QFD-based hybrid fuzzy MCDM approach for performance evaluation: A case of smart bike-sharing programs in Changsha", Journal of Cleaner Production, vol. 171, pp. 1068-1083, 2018.
[32] Y. Wu, C. Xu, and T. Zhang, "Evaluation of renewable power sources using a fuzzy MCDM based on cumulative prospect theory: A case in China", Energy, vol. 147, pp. 1227-1239, 2018.
[33] S. Opricovic, and G. H. Tzeng, "Extended VIKOR method in comparison with outranking methods", European Journal of Operational Research, vol. 178, pp. 514-529, 2007.
[34] A. Sanayei, S. F. Mousavi, and A. Yazdankhah, "Group decision making process for supplier selection with VIKOR under fuzzy environment", Expert Systems with Applications, vol. 37, pp. 24-30, 2010.