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# FUZZY QUALITY FUNCTION DEPLOYMENT APPROACH FOR SELECTION OF MINERAL WATER MANUFACTURER COMPANIES

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## ABSTRACT

### Aim of the study
The quality of mineral waters produced in our country is gaining importance because the number of companies operating in the mineral water sector increased rapidly over the last few years and the demand and export rate for mineral water increased. In this study, a multi-criteria decision making model for companies that produce mineral water production in Turkey was created by using Quality Function Deployment (QFD).

### Material and methods
The House of Quality, which forms the basis of KFY, has been assembled in 7 steps. Company selection criteria (Customer requirements) in the model were collected in 2 different ways. This formats combined in the goal programming model, the importance of company selection criteria was found by solving the model. In order to avoid ambiguity in linguistic expressions and to better reflect the truth, fuzzy triangular numbers have been used. The weights of the firms are calculated according to each other considering both the manufacturer side and the customer side.

### Results
Company selection criteria for mineral water and their importance were found. Possible technical characteristics to meet these criteria have been obtained. All of these customer and firm data have been combined to create a ranking for companies producing mineral water.

**Conclusions**
Determining the order of importance of the companies helps the manufacturers to take decisions on the basis of strategy planning. Even if the work is done in the natural mineral water sector, it is easy to adapt to the drinking water sector

**Key words:** Mineral Water Industry, Quality Function Deployment, Multi-criteria Decision Making

## INTRODUCTION

In developed societies, bottled or packed mineral water or natural spring water is as drinking water, and this is getting widespread nowadays. The amount of mineral water consumed per person in Europe is 100 liters per year. In our country, it reached 200 liters in 1990 and today it 3 liters [1].
The natural mineral water sector in Turkey started with the establishment of the Kızılay Maden Waters' Establishments by the Turkish Red Crescent Society in 1926. For many years, the Turkish Red Crescent Society has remained the only producer in the production of mineral water. The companies that were established in the following years answered the regional needs. In recent years, there has been an upsurge in the mineral water sector with the legal regulations. 230 from the current source of mineral water bottled commercially in Turkey is about 30 and a total annual production is at around 200 million liters [1]. According to this, 1% of the total mineral water potential in Turkey can be assessed.
In this study, a multi-criteria decision making model for companies that produce mineral water in Turkey was established by using Quality Function Deployment (QFD).
Quality Function Deployment was a method introduced by Akao in 1966. The method was applied by Mitsubishi Heavy Industries Ltd. in Japan in 1972. In the literature QFD technique is used for product development in general terms. However, there are also studies that use QFD as a multi-criteria decision making technique [2-10].
In the study of QFD, determining and ranking the importance ratings of customer expectations is one of the most fundamental issues. Chan et al. (1999) and Wang and Chin (2011) prioritize customer expectations in their work [11-12].
Zaitsev and Dror (2013) in order to improve the quality of tap water by the water supplier, they have formed a structure where the technical and economic factors as well as the voices of the customers are rested. They created House of Water Quality for this [13].
In the literature, there was no study evaluating the mineral water from the customer's perspective. In this study, customer needs for mineral water, technical requirements to meet these needs, and major companies operating in the sector have been identified and compared.
The paper is organized as follows: in Section 2, we mentioned the traditional QFD and fuzzy QFD method. Then we discussed the proposed method and applied the proposed method to companies that produce mineral water. Finally, a discussion of the proposed model and conclusion are presented in Sections 3 and 4.

## MATERIALS AND METHODS

In this section, firstly, the utilized technique is mentioned in Quality Function Deployment, discussed the proposed method and then mineral water manufactures are used to illustrate the application of the proposed model.

### 1. Quality Function Deployment

In addition to ensuring the continuity of quality control and quality improvement activities from the beginning to the end of the production process, they need to be customer-focused. Quality Function Deployment (QFD) Technique transforms customer voice into technical characteristics by providing customer focus. The method involves developing four matrixes,

or 'houses', that we enter by degrees as a project for a given product or production process is developed on increasingly specific levels (Akao, 1990)[14].

The QFD team must be installed before applying the QFD technique. There are specialists in the firm and the clients of the company where the work was done. The main step of QFD is to establish a House of Quality consisting of customer and technical part. The rows of the House of Quality include customer expectations, there are technical characteristics in the columns, relationships of technical characteristics in the roof, the relationship between customer expectations and technical characteristics in the main body of House of Quality. The House of Quality established in the study is shown in Figure 1.

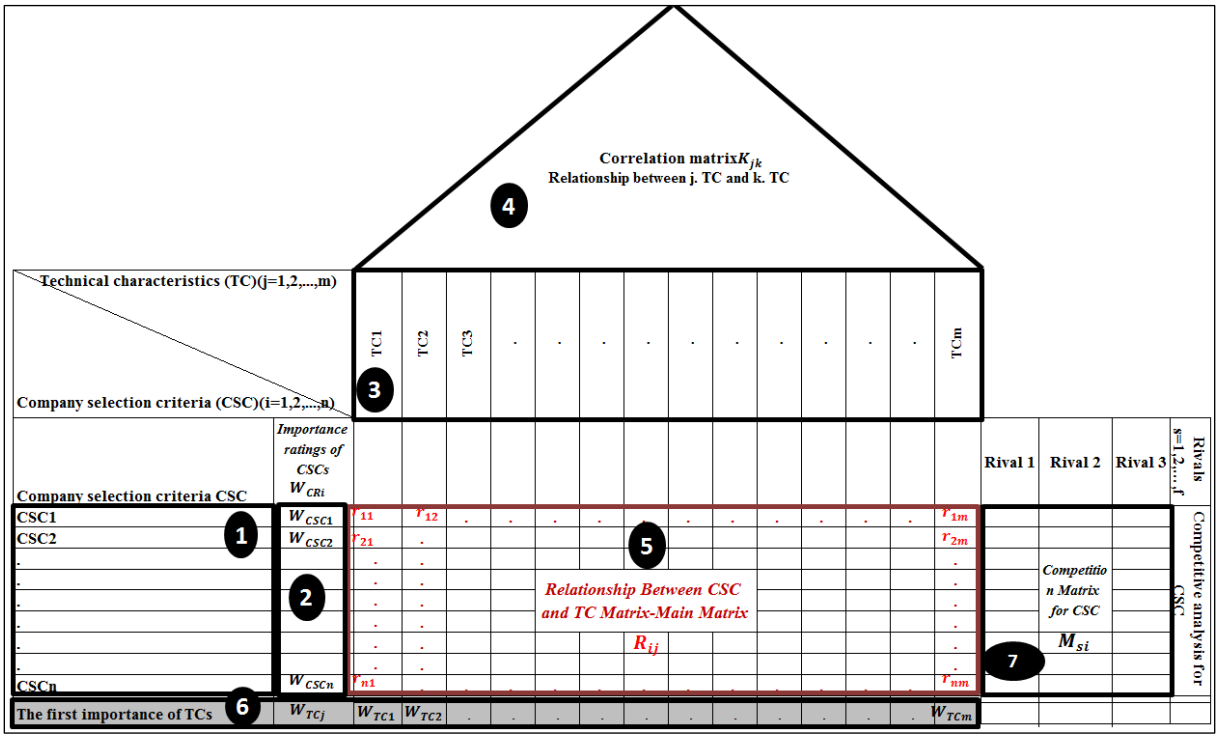


**Figure 1. House of Quality for the selection process**

The House of Quality in the study consists of 7 steps. In the first step, the specified customer requirements are placed in the rows. In the second step, the importance customer requirements are determined and placed in the relevant rows. In the third step, the technical characteristics to meet customer expectations are determined and placed in the columns. In the fourth step, relations between technical characteristics are determined and the roof matrix is formed. The main matrix in which the relationship between customer requirements and technical characteristics is determined is created in the fifth step. In the sixth step, the importance ratings of the technical characteristics are calculated. In the last step, importance ratios are calculated by evaluating each competitor in terms of customer expectations.
In the planning processes involving experts' uncertain and subjective assessments especially steps 4, 5 and 7; classical QFD seems to be inadequate. In traditional QFD, most of the input variables are assumed to be crisp values but QFD contains linguistic data that is inherently ambiguous because it is a method that transforms the customer's voice into product characteristics [15]. Therefore fuzzy logic is used when relations are determined in the QFD methodology. With the help of the fuzzy set theory, the linguistic data can be processed

according to approximate accuracy. Fuzzy Logic allows transforming the subjective and ambiguous expressions of decision makers into measurable data. When linguistic data is used in QFD, some factors can affect the results, such as the type of fuzzy numbers, the methods of defuzzfication, and the degree of fuzzification of fuzzy numbers.

## 2. Recommended method

The steps of the selection model for mineral water companies are shown in Figure 2. In this study, House of Quality consists of roughly 4 steps and 7 steps in detail. Determination of customer voice, collection of company voice, combining of data (formation of House of Quality) and analysis and interpretation of results are four steps of House of Quality. In the section of customer voice, importance ratings of customer requirements (company selection criteria) are determined by Goal Programming. Collection of company voice is second section of House of Quality. In this section determined technical characteristics which satisfied customer requirements and competing companies. In the third section of House of Quality, calculated interrelationship technical characteristics, relationship between customer requirements and technical characteristics and relationship between customer requirements and companies. The final step is based on the interpretation of the House of Quality created. The customer requirements in the classical KFY are called the company selection criterion in this study.

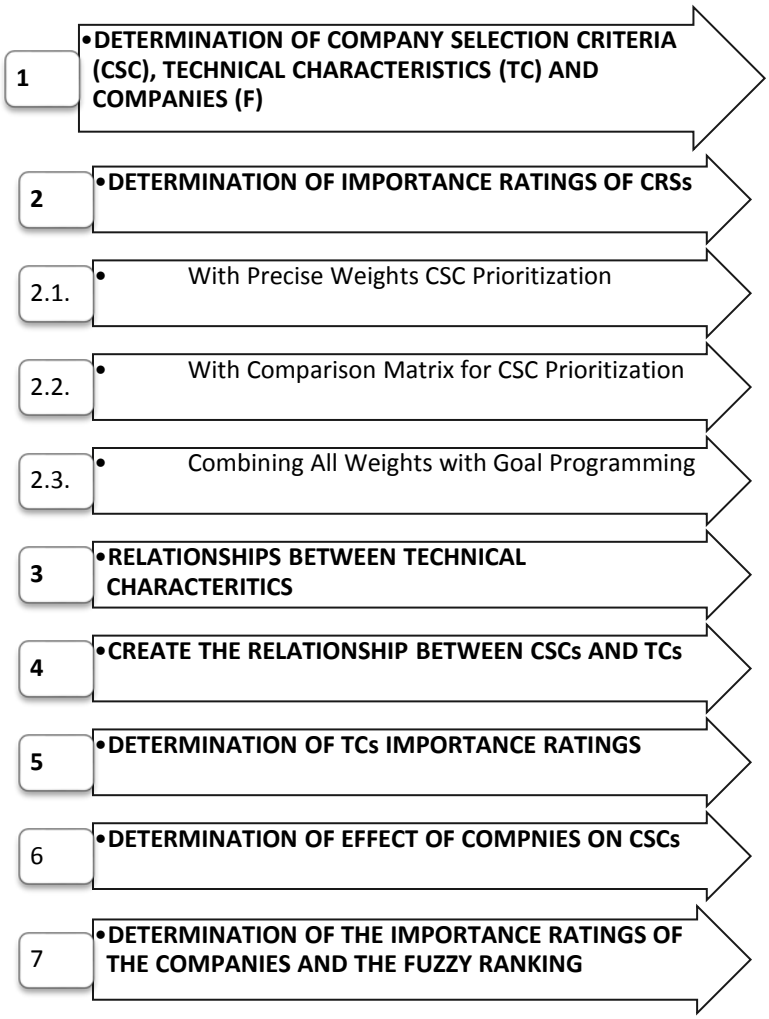


Figure 2. Steps of the Model

The Group Decision Making Approach has been used in the calculation of company selection criteria and their importance and in this study step 2 [12]. Questionnaires were presented to customers in different formats, taking into account the level of education, social and cultural status of the customers. These formats are in the form of 1-9 Likert scaling and binary comparison matrix. These two formats are combined in the Goal Programming Model. With the resolution of this model, importance ratings of company selection criteria ($W_{CSC}$) are assigned.

Each goal is handled as a constraint in the goal programming and the target values set for the objectives are written on the right hand side of the objective constraint. From these target values, deviations in the positive and negative direction are tried to be minimized. The general structure of the goal programming model is shown below.

Decision variables and notations;
$n =$ Number of company selection criteria (CSC),(*i=1,2,…,n*), (The number of target)
$W_{CRi} =$ Importance ratings of company selection criteria *i*
$e_{i+}^{(l)} =$ Positive deviation of the company selection criteria *i* in format *l*
$e_{i-}^{(l)} =$ Negative deviation of the company selection criteria *i* in format *l*
$\lambda_f =$ Weight of format *l*
$i = 1,2, \dots ,8$ , (Customer requirements)
$l = 1,2$ , (Formats: Precise weight and comparison matrix)
$b_i$= Target to achieved goal *i*

$$Min\, J_i = [\sum_{i=1}^{n} \lambda_i (e_{i+} + e_{i-})] \quad (1)$$
$$f_i(x) - e_{i+} + e_{i-} = b_i \quad (2)$$
$$e_{i-}, e_{i+} \geq 0 \quad (3)$$

In Goal Programming created in the customer part of the Quality Function Deployment, each goal is company selection criteria and the right side of the constraints is importance rating of company selection criteria (Formula 2). The objective function (Formula 1) is to reduce the negative and positive deviations from the importance ratings of company selection criteria.

The constraints and objective functions used in the Goal Programming Model used in the study are shown in Table 1. Since two types of format are used in the study, two types of constraints are used. The first constraint is that the assigned customer requirements weights equal to the target values. In comparison matrix the second type of constraint inconsistency equals to zero [12].

**Table 1. Constraints and Objective Functions Used in Goal Programming for QFD**

| ***Formats*** | ***Constraints*** | ***Objective function*** |
|---|---|---|
| Precise weights | $w_i - e_{i+}^{(l)} + e_{i-}^{(l)} = w_i^{(l)}$ (1.constraint) | $J_1 = \sum_{leG_1} \sum_{i=1}^{n} \lambda_1 (e_{i+}^{(l)} + e_{i-}^{(l)})$ |
| Comparison matrix | $(A^{(l)} - nI)W - E_{+}^{(l)} + E_{-}^{(l)} = 0$ (2.constraint) | $J_2 = \sum_{leG_2} \sum_{i=1}^{n} \lambda_2 (e_{i+}^{(l)} + e_{i-}^{(l)})$ |

Relationship between technical characteristics and company selection criteria, companies and company selection criteria also relationship between technical characteristics are expressed by fuzzy triangular numbers in order to cope with ambiguity in linguistic expressions, better represent the truth and create a quantitative basis.

### A Case Study of Model in Mineral Water Sector

The proposed method has been applied to 8 mineral water producing companies in Turkey. A Quality Function Deployment crew was established from among the experts and customers identified in one of them. The steps of the application are described below.

*Step 1. Determination of Company selection criteria (CSC), Companies (F), Technical characteristics (TC)*: QFD team has defined 7 technical characteristics, 8 company selection criteria and 8 companies. These are shown in Table 2. The customer requirements in the classical KFY are called the company selection criterion in this study.

$n$ = Number of company selection criteria (CR),($i=1,2,\ldots,n$)
$m$ =Number of technical characteristics (TC),($j=1,2,\ldots,m$)
$f$ = Number of companies (F),($s=1,2,\ldots,f$)

**Table 2. Company Selection Criteria and Technical Characteristics**

| ***Company Selection Criteria (What?)*** | | ***Technical characteristics (How?)*** | |
|---|---|---|---|
| $CSC_1$ | Ease of application | $TC_1$ | Hygienic production conditions |
| $CSC_2$ | Non-recyclable packaging | $TC_2$ | Proximity to the plant's source |
| $CSC_3$ | Packages (6 pieces) | $TC_3$ | Air permeability rating of packaging |
| $CSC_4$ | Less processing | $TC_4$ | Storage conditions |
| $CSC_5$ | Fruit flavor intensity | $TC_5$ | Water mineral concentration |
| $CSC_6$ | Good taste and smell | $TC_6$ | On-time delivery |
| $CSC_7$ | Promotions and campaigns | $TC_7$ | Company management skills |
| $CSC_8$ | Reasonable price | | |

*Step 2. Determination of importance ratings of company selection criteria*: Importance ratings of company selection criteria are calculated by using 1-9 simple Likert scaling in the time constraint environment for a quicker conversation with customers who are difficult to reach. The averages of the scores given by each customer were taken and these averages were normalized and converted into values between 0-1 and these are shown in Table 3.

**Table 3. Importance Ratings of Company Selection Criteria with Precise Weight Scaling**

| *Company selection criteria* | *Customer 1* | *Customer 2* | *Customer 3* | *Customer 4* | *Average* | *Normalized value* |
|---|---|---|---|---|---|---|
| Ease of application | 7 | 3 | 5 | 5 | 5 | **0,12** |
| Non-recyclable packaging | 3 | 1 | 3 | 3 | 2,5 | **0,06** |
| Packages (6 pieces) | 3 | 1 | 3 | 3 | 2,5 | **0,06** |
| Less processing | 7 | 7 | 7 | 7 | 7 | **0,17** |
| Fruit flavor intensity | 3 | 3 | 5 | 5 | 4 | **0,10** |
| Good taste and smell | 9 | 9 | 7 | 7 | 8 | **0,20** |
| Promotions and campaigns | 1 | 3 | 5 | 5 | 3,5 | **0,09** |
| Reasonable price | 9 | 7 | 9 | 7 | 8 | **0,20** |

In an environment where there is no time constraint, comparison matrices have been established for CRs as a result of face-to-face interviews with customers (Table 4). The consistency ratio of the matrix formed by each customer is calculated and the matrices whose consistency ratio is lower than 0.1 are considered.

Table 4. CSC Comparison Matrix

| *Company selection criteria* | | **CS $C_1$** | **CS $C_2$** | **CS $C_3$** | **CS $C_4$** | **CS $C_5$** | **CS $C_6$** | **CS $C_7$** | **CS $C_8$** |
|---|---|---|---|---|---|---|---|---|---|
| Ease of application | **CS $C_1$** | 1,00 | 5,00 | 5,50 | 0,22 | 2,50 | 0,14 | 4,00 | 0,16 |
| Non-recyclable packaging | **CS $C_2$** | 0,20 | 1,00 | 1,50 | 0,16 | 0,33 | 0,12 | 0,67 | 0,13 |
| Packages (6 pieces) | **CS $C_3$** | 0,19 | 0,83 | 1,00 | 0,16 | 0,27 | 0,12 | 0,50 | 0,13 |
| Less processing | **CS $C_4$** | 5,00 | 6,50 | 6,50 | 1,00 | 6,00 | 0,30 | 5,29 | 0,67 |
| Fruit flavor intensity | **CS $C_5$** | 0,50 | 3,00 | 4,00 | 0,20 | 1,00 | 0,14 | 2,00 | 0,16 |
| Good taste and smell | **CS $C_6$** | 7,50 | 8,50 | 8,50 | 3,50 | 7,50 | 1,00 | 7,00 | 2,50 |
| Promotions and campaigns | **CS $C_7$** | 0,42 | 2,00 | 2,50 | 1,86 | 0,67 | 0,15 | 1,00 | 0,13 |
| Reasonable price | **CS $C_8$** | 6,50 | 8,00 | 8,00 | 2,00 | 6,50 | 0,50 | 8,00 | 1,00 |

These two different formats are combined with the goal programming (Formula 1-3) model. Importance ratings of company selection criteria found by resolving this model:

$W_{CR1} = 0{,}08, W_{CR2} = 0{,}02, W_{CR3} = 0{,}01, W_{CR4} = 0{,}19, W_{CR5} = 0{,}04, W_{CR6} = 0{,}36\,, W_{CR7} = 0{,}07, W_{CR8} = 0{,}23$

*Step 3. Determination of Relationship between Technical characteristics (TC) and TC Average Correlation Value (Correlation Matrix)*: Triangular fuzzy numbers were used the degree of relationship between technical characteristics. The linguistic scale used is also shown in Figure 3.

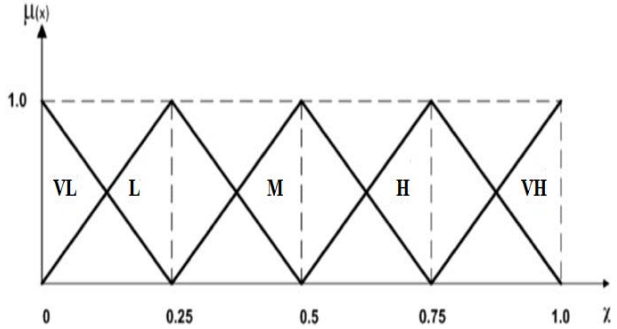


**Figure 3. Linguistic Scale (Very low: (0,0,0.25), Low: (0,0.25,0.5), Medium: (0.25,0.5,0.75), High: (0.5,0.75,1), Very high: (0.75,1,1))**

The average of the fuzzy scores of each technical characteristic is calculated by the following Formula 4 and is shown in Table 5.

$m =$ The number of technical characteristics (TC),(*j=1,2,...,m*)
$\hat{k}_{jk} =$ The degree of the fuzzy relationship between TC *j* and TC *k*
$\hat{k}_j =$ Fuzzy average correlation value of TC *j*

$$k_j = \frac{1}{m-1} \sum_{j \neq k}^{m} (k_{jk}) \qquad (4)$$

**Table 5. Average Fuzzy Correlation Value of Technical Characteristics**

| | Lower (L) | Medium (M) | Upper (U) |
|---|---|---|---|
| **TC1** | 0,23 | 0,34 | 0,50 |
| **TC2** | 0,22 | 0,34 | 0,50 |
| **TC3** | 0,19 | 0,30 | 0,46 |
| **TC4** | 0,13 | 0,35 | 0,48 |
| **TC5** | 0,17 | 0,23 | 0,39 |
| **TC6** | 0,17 | 0,24 | 0,37 |
| **TC7** | 0,20 | 0,29 | 0,45 |

*Step 4. Establishing the Relationship between TC and CSC (Main Matrix)*: In this section, the main part of the House of Quality was created. While the relationship between TC and CSC was determined, it was again benefited from triangular fuzzy numbers (Figure 3). The average relationship matrix between company selection criteria and technical characteristics as a result of interviews with experts is shown in Figure 4. Figure 5 is House of Quality created when the correlation matrix is taken into consideration.

| | Technical Characteristics / Customer Requirements | Importance ratings of CRs | Hygienic production conditions | | | Proximity to the plant's source | | | Air permeability rating of packaging | | | Storage conditions | | | Water mineral concentration | | | On-time delivery | | | Company management skills | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.2,0.4,0.6 | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0.1,0.2,0.3 | | | 0.1,0.3,0.4 | | | 0.1,0.3,0.5 | | | 0.2,0.3,0.5 | | |
| | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0.1,0.3,0.5 | | | 0.2,0.3,0.5 | | | 0,0.1,0.3 | | | 0.1,0.2,0.4 | | | 0.2,0.3,0.5 | | |
| | | | 0.1,0.2,0.3 | | | 0.1,0.3,0.4 | | | 0.1,0.3,0.5 | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0,0,0.2 | | | 0,0,0.2 | | |
| | | | 0.2,0.3,0.5 | | | 0,0.1,0.3 | | | 0.1,0.2,0.4 | | | 0.1,0.3,0.5 | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0,0,0.2 | | |
| | | | 0.1,0.3,0.5 | | | 0.1,0.3,0.5 | | | 0.2,0.3,0.5 | | | 0.1,0.3,0.5 | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0,0,0.2 | | |
| | | | 0.2,0.4,0.6 | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0.1,0.2,0.4 | | | 0,0,0.2 | | | 0,0,0.2 | | | | | |
| Customer Requirements | Ease of application | 0,08 | 0,00 | 0,01 | 0,03 | 0,00 | 0,00 | 0,02 | 0,03 | 0,05 | 0,07 | 0,00 | 0,00 | 0,02 | 0,00 | 0,00 | 0,02 | 0,00 | 0,00 | 0,02 | 0,00 | 0,01 | 0,03 |
| | Non-recyclable packaging | 0,02 | 0,00 | 0,01 | 0,01 | 0,00 | 0,00 | 0,01 | 0,01 | 0,01 | 0,02 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,01 | 0,00 | 0,01 | 0,01 |
| | Packages (6 pieces) | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,01 |
| | Less processing | 0,19 | 0,05 | 0,07 | 0,12 | 0,05 | 0,10 | 0,14 | 0,00 | 0,02 | 0,07 | 0,00 | 0,02 | 0,07 | 0,07 | 0,12 | 0,17 | 0,02 | 0,05 | 0,10 | 0,00 | 0,02 | 0,07 |
| | Fruit flavor intensity | 0,04 | 0,00 | 0,00 | 0,01 | 0,00 | 0,01 | 0,02 | 0,00 | 0,00 | 0,01 | 0,00 | 0,01 | 0,02 | 0,01 | 0,02 | 0,03 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,01 |
| | Good taste and smell | 0,36 | 0,28 | 0,37 | 0,37 | 0,14 | 0,23 | 0,32 | 0,19 | 0,28 | 0,37 | 0,23 | 0,32 | 0,37 | 0,28 | 0,37 | 0,37 | 0,05 | 0,14 | 0,23 | 0,00 | 0,05 | 0,14 |
| | Promotions and campaigns | 0,07 | 0,01 | 0,02 | 0,04 | 0,00 | 0,02 | 0,04 | 0,00 | 0,00 | 0,02 | 0,01 | 0,02 | 0,04 | 0,03 | 0,04 | 0,06 | 0,04 | 0,05 | 0,07 | 0,04 | 0,06 | 0,07 |
| | Reasonable price | 0,23 | 0,12 | 0,17 | 0,23 | 0,17 | 0,23 | 0,23 | 0,03 | 0,09 | 0,14 | 0,09 | 0,14 | 0,20 | 0,12 | 0,17 | 0,23 | 0,14 | 0,20 | 0,23 | 0,14 | 0,20 | 0,23 |
| | W*(CSC) | | 0,056 | 0,081 | 0,101 | 0,045 | 0,072 | 0,097 | 0,031 | 0,056 | 0,088 | 0,041 | 0,064 | 0,090 | 0,062 | 0,090 | 0,110 | 0,031 | 0,055 | 0,083 | 0,024 | 0,044 | 0,071 |

**Figure 4. House of Quality without Considering Correlation Matrix**

| | Technical Characteristics / Customer Requirements | Importance ratings of CRs | Hygienic production conditions | | | Proximity to the plant's source | | | Air permeability rating of packaging | | | Storage conditions | | | Water mineral concentration | | | On-time delivery | | | Company management skills | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 0.2,0.4,0.6 | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0.1,0.2,0.3 | | | 0.1,0.3,0.4 | | | 0.1,0.3,0.5 | | | 0.2,0.3,0.5 | | |
| | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0.1,0.3,0.5 | | | 0.2,0.3,0.5 | | | 0,0.1,0.3 | | | 0.1,0.2,0.4 | | | 0.2,0.3,0.5 | | |
| | | | 0.1,0.2,0.3 | | | 0.1,0.3,0.4 | | | 0.1,0.3,0.5 | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0,0,0.2 | | | 0,0,0.2 | | |
| | | | 0.2,0.3,0.5 | | | 0,0.1,0.3 | | | 0.1,0.2,0.4 | | | 0.1,0.3,0.5 | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0,0,0.2 | | |
| | | | 0.1,0.3,0.5 | | | 0.1,0.3,0.5 | | | 0.2,0.3,0.5 | | | 0.1,0.3,0.5 | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0,0,0.2 | | |
| | | | 0.2,0.4,0.6 | | | 0,0.1,0.3 | | | 0.2,0.4,0.6 | | | 0.1,0.2,0.4 | | | 0,0,0.2 | | | 0,0,0.2 | | | | | |
| Customer Requirements | Ease of application | 0,08 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,01 | 0,01 | 0,02 | 0,03 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,01 |
| | Non-recyclable packaging | 0,02 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| | Packages (6 pieces) | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| | Less processing | 0,19 | 0,01 | 0,02 | 0,06 | 0,01 | 0,03 | 0,07 | 0,00 | 0,01 | 0,03 | 0,00 | 0,01 | 0,03 | 0,01 | 0,03 | 0,07 | 0,00 | 0,01 | 0,04 | 0,00 | 0,01 | 0,03 |
| | Fruit flavor intensity | 0,04 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,01 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 | 0,00 |
| | Good taste and smell | 0,36 | 0,06 | 0,12 | 0,18 | 0,03 | 0,08 | 0,16 | 0,04 | 0,08 | 0,17 | 0,03 | 0,11 | 0,18 | 0,05 | 0,08 | 0,15 | 0,01 | 0,03 | 0,09 | 0,00 | 0,01 | 0,06 |
| | Promotions and campaigns | 0,07 | 0,00 | 0,01 | 0,02 | 0,00 | 0,01 | 0,02 | 0,00 | 0,00 | 0,01 | 0,00 | 0,01 | 0,02 | 0,00 | 0,01 | 0,02 | 0,01 | 0,01 | 0,03 | 0,01 | 0,02 | 0,03 |
| | Reasonable price | 0,23 | 0,03 | 0,06 | 0,11 | 0,04 | 0,08 | 0,11 | 0,01 | 0,03 | 0,07 | 0,01 | 0,05 | 0,10 | 0,02 | 0,04 | 0,09 | 0,02 | 0,05 | 0,09 | 0,03 | 0,06 | 0,10 |
| | W*(CSC) | | 0,013 | 0,027 | 0,050 | 0,010 | 0,024 | 0,048 | 0,006 | 0,017 | 0,040 | 0,005 | 0,022 | 0,043 | 0,010 | 0,021 | 0,043 | 0,005 | 0,013 | 0,031 | 0,005 | 0,013 | 0,032 |

**Figure 5. House of Quality When Considering Correlation Matrix**

*Step 5. Determination of importance ratings of TC*: When the first and last fuzzy importance ratings of technical characteristics are determined, the following formulas are used respectively (Formula 5, 6). The values found are shown in Table 6.

$n$ = The number of company selection criteria (CSC),(*i=1,2,…,n*)
$m$ = The number of technical characteristics (TC),(*j=1,2,…,m*)
$\hat{r}_{ij}$ = The degree of fuzzy relationship between CSC *i* and TC *j*
$\widehat{W}_{TCj}$ = Fuzzy first importance level of TC *j* (when the correlation matrix is not considered)
$\widehat{W}^{*}_{TCj}$ = Fuzzy last importance level of TC *j* (when the correlation matrix is considered)
$W_{CSCi}$= Importance ratings of company selection criteria *i* (From Step 2)
$\hat{k}_j$ = Fuzzy average correlation value of TC *j* (From Formula 4, in Step 3)

$$\widehat{W}_{TCj} = \sum_{i=1}^{n} \hat{r}_{ij} * W_{CSCi} \quad (5)$$

$$\widehat{W^{*}_{TCj}} = \widehat{W}_{TCj} * \hat{k}_j \quad (6)$$

Table 6. The first and last fuzzy importance ratings of TCs

| | *Without Considering Correlation Matrix (first)* $\widehat{W}_{TCj}$ | | | *When Considering Correlation Matrix (last)* $\widehat{W^*_{TCj}}$ | | |
|---|---|---|---|---|---|---|
| ***Technical characteristics*** | ***Lower (L)*** | ***Medium (M)*** | ***Upper (U)*** | ***Lower (L)*** | ***Medium (M)*** | ***Upper (U)*** |
| Hygienic production conditions | 0,056 | 0,081 | 0,101 | 0,013 | 0,027 | 0,050 |
| Proximity to the plant's source | 0,045 | 0,072 | 0,097 | 0,010 | 0,027 | 0,048 |
| Air permeability rating of packaging | 0,031 | 0,056 | 0,088 | 0,006 | 0,017 | 0,040 |
| Storage conditions | 0,041 | 0,064 | 0,090 | 0005 | 0,022 | 0,043 |
| Water mineral concentration | 0,062 | 0,090 | 0,11 | 0,010 | 0,021 | 0,043 |
| On-time delivery | 0,031 | 0,055 | 0,083 | 0,005 | 0,013 | 0,031 |
| Company management skills | 0,024 | 0,044 | 0,071 | 0,005 | 0,013 | 0,032 |

In Table 6, “water mineral value” was lower when considering the relation between technical characteristics. The reason for this is that the “mineral value of the water” has a low correlation with other technical requirements.

*Step 6. Impact of Company on CSC (Competition Matrix)*: The effect of each company on company selection criteria is expressed by triangular fuzzy numbers (Figure 3). Figure 6 shows the direct fuzzy scores that companies receive in each company selection criteria at House of Quality.

| | | | | *Competition matrix for CSCs* | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | The importance ratings of CSCs | | | Company 1 | | | Company 2 | | | Company 3 | | | Company 4 | | | Company 5 | | | Company 6 | | | Company 7 | | | Company 8 | | |
| Ease of application | 0,000 | 0,002 | 0,008 | 0,008 | 0,024 | 0,050 | 0,005 | 0,017 | 0,044 | 0,002 | 0,010 | 0,031 | 0,002 | 0,007 | 0,025 | 0,005 | 0,017 | 0,038 | 0,003 | 0,014 | 0,038 | 0,006 | 0,020 | 0,044 | 0,003 | 0,014 | 0,038 |
| Non-recyclable packaging | 0,000 | 0,000 | 0,001 | 0,004 | 0,015 | 0,042 | 0,004 | 0,015 | 0,042 | 0,001 | 0,009 | 0,030 | 0,001 | 0,009 | 0,030 | 0,004 | 0,015 | 0,036 | 0,002 | 0,012 | 0,036 | 0,004 | 0,015 | 0,036 | 0,002 | 0,012 | 0,036 |
| Packages (6 pieces) | 0,000 | 0,000 | 0,000 | 0,001 | 0,008 | 0,030 | 0,001 | 0,008 | 0,030 | 0,001 | 0,008 | 0,030 | 0,001 | 0,006 | 0,025 | 0,001 | 0,006 | 0,025 | 0,000 | 0,004 | 0,020 | 0,000 | 0,004 | 0,020 | 0,002 | 0,010 | 0,035 |
| Less processing | 0,007 | 0,022 | 0,062 | 0,002 | 0,014 | 0,037 | 0,001 | 0,008 | 0,027 | 0,001 | 0,008 | 0,027 | 0,001 | 0,008 | 0,027 | 0,002 | 0,014 | 0,037 | 0,001 | 0,011 | 0,032 | 0,000 | 0,003 | 0,016 | 0,001 | 0,011 | 0,032 |
| Fruit flavor intensity | 0,000 | 0,000 | 0,002 | 0,004 | 0,013 | 0,038 | 0,005 | 0,015 | 0,038 | 0,001 | 0,008 | 0,027 | 0,001 | 0,008 | 0,027 | 0,001 | 0,008 | 0,027 | 0,004 | 0,013 | 0,038 | 0,003 | 0,008 | 0,027 | 0,004 | 0,013 | 0,032 |
| Good taste and smell | 0,079 | 0,196 | 0,364 | 0,003 | 0,011 | 0,031 | 0,003 | 0,011 | 0,031 | 0,000 | 0,003 | 0,015 | 0,002 | 0,008 | 0,027 | 0,001 | 0,005 | 0,019 | 0,002 | 0,008 | 0,027 | 0,003 | 0,010 | 0,027 | 0,003 | 0,010 | 0,031 |
| Promotions and campaigns | 0,002 | 0,004 | 0,010 | 0,002 | 0,009 | 0,028 | 0,002 | 0,009 | 0,028 | 0,001 | 0,005 | 0,020 | 0,001 | 0,006 | 0,024 | 0,001 | 0,005 | 0,020 | 0,001 | 0,006 | 0,024 | 0,000 | 0,002 | 0,012 | 0,002 | 0,008 | 0,028 |
| Reasonable price | 0,383 | 0,082 | 0,154 | 0,006 | 0,019 | 0,043 | 0,003 | 0,013 | 0,038 | 0,003 | 0,013 | 0,038 | 0,003 | 0,013 | 0,038 | 0,000 | 0,005 | 0,022 | 0,001 | 0,008 | 0,027 | 0,001 | 0,008 | 0,027 | 0,003 | 0,013 | 0,038 |
| Ortalamalar | 0,059 | 0,038 | 0,075 | 0,004 | 0,014 | 0,037 | 0,003 | 0,012 | 0,035 | 0,001 | 0,008 | 0,027 | 0,002 | 0,008 | 0,028 | 0,002 | 0,009 | 0,028 | 0,002 | 0,010 | 0,030 | 0,002 | 0,009 | 0,026 | 0,003 | 0,011 | 0,034 |

**Figure 6. The Points the Company Has Received in Company selection criteria (Competition matrix)**

In order to determine the company importance ratings, firstly the total value of the importance ratings of each company selection criteria on the each technical characteristics has to be determined. Thus, the importance ratings of the companies were determined by considering the technical requirements and company selection criteria. Figure 6 also shows the total fuzzy importance ratings of company selection criteria. The following Formula 7 is used for this.

$\widehat{W}^*_{CSCi}$= The total fuzzy importance ratings of company selection criteria *i*,

$W_{CSCi}$= The first importance rating of company selection criteria *i* (Value found in the result of Goal Programming)

$$\widehat{W}^{*}_{CSCi} = \sum_{j=1}^{m} (\hat{r}_{ij} * W_{CSCi}) \quad (7)$$

*Step 7. Identification of Companies Importance Ratings and Construction of Fuzzy Sorting*: The importance ratings of the companies are formed in two ways. It is calculated without considering the weights of company selection criteria ($\widehat{W}^{*}_{CSCi}$) first and the following Formula 8 is used.

$f$ = The number of companies (F),(*s=1,2,…,f*)
$\widehat{W}_{Fs}$ = The first fuzzy importance rating of company *s* (Without Considering importance of CSCs)
$\widehat{W}^{*}_{Fs}$ = The last fuzzy importance rating of company *s* (When Considering importance of CSCs)
$\widehat{m}_{si}$ = The fuzzy importance rating of company *s* on CSC *i*

$$\widehat{W}_{Fs} = \sum_{i=1}^{n} \widehat{m}_{si} \quad (8)$$

Later, the last fuzzy importance ratings of companies were found using last fuzzy importance ratings of company selection criteria ($\widehat{W}^{*}_{CSCi}$) by using Formula 9.

$$\widehat{W^{*}_{Fs}} = \sum_{i=1}^{n} (\widehat{m}_{si} * \widehat{W}^{*}_{CSCi}) \quad (9)$$

The fuzzy importance ratings of the companies are calculated and listed in Table 7. In order to be able to decide, these fuzzy numbers need to be sorted. A lot of research has been done on the ordering of fuzzy numbers and different methods have been introduced. The fuzzy values obtained in this study are ordered by the fuzzy ranking method used by Kwong and Bai (2003) [16].When a triangular fuzzy number is given as M = (a, o, u), the defuzzification is performed; $M_d = \frac{a+4o+ü}{6}$

**Table 7. The fuzzy importance ratings of company and defuzzification values**

| | ***Without Considering importance of CSCs ($\widehat{W}_{Fs}$)*** | | | | | ***When Considering importance of CSCs ($\widehat{W^{*}_{Fs}}$)*** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | ***L*** | ***M*** | ***U*** | $M_d$ | ***Rank*** | ***L*** | ***M*** | ***U*** | $M_d$ | ***Rank*** |
| F1 | 0,004 | 0,014 | 0,037 | 0,0164 | 1 | 0,0002 | 0,0005 | 0,0028 | 0,00087 | 1 |
| F2 | 0,003 | 0,012 | 0,035 | 0,0145 | 2 | 0,0002 | 0,0005 | 0,0026 | 0,00078 | 2 |
| F3 | 0,001 | 0,008 | 0,027 | 0,0102 | 8 | 0,0001 | 0,0003 | 0,0020 | 0,00056 | 8 |
| F4 | 0,002 | 0,008 | 0,028 | 0,0104 | 7 | 0,0001 | 0,0003 | 0,0021 | 0,00057 | 6-7 |
| F5 | 0,002 | 0,009 | 0,028 | 0,0112 | 5 | 0,0001 | 0,0004 | 0,0021 | 0,00061 | 5 |
| F6 | 0,002 | 0,010 | 0,030 | 0,0117 | 4 | 0,0001 | 0,0004 | 0,0023 | 0,00064 | 4 |
| F7 | 0,002 | 0,009 | 0,026 | 0,0105 | 6 | 0,0001 | 0,0003 | 0,0020 | 0,00057 | 6-7 |
| F8 | 0,030 | 0,011 | 0,034 | 0,0137 | 3 | 0,002 | 0,0040 | 0,0025 | 0,00074 | 3 |

## RESULT AND DISCUSSION

In this study, mineral water producer companies are listed by considering the company selection criteria for the mineral water product and the technical characteristics that will meet these requirements.

Company selection criteria and importance ratings have been collected in different formats. By assigning different weights to these formats, customer priorities can be calculated with final importance ratings. This may lead to closer results. In this study, the weights of all formats are assumed to be the same. According to the goal programming, the most important customer requirement is "good taste and smell" and followed by "reasonable price".

The importance ratings of companies are found in two different ways; without the weights of the company selection criteria and with the weights of the company selection criteria. It is seen that the order of fuzzy importance in the order made by considering company selection criteria is smaller than the other order and values close to each other (Table 7). The fuzzy importance ratings of the companies are ordered by using Kwong and Bai's method. Accordingly, the order of the firms can be shown as F1> F2> F8> F6> F5> F4 = F7> F3.

In the case where the weights of company selection criteria are taken into account, the effect of each company on each company selection criteria and importance ratings of company selection criteria in terms of technical characteristics are used to calculate the importance ratings of the company. Thus, the evaluation of the companies by both the customer and the firm has resulted in better representation of the economic, technical and social conditions.

In this study, triangular fuzzy numbers were used in determining the degree of relationship between company selection criteria and technical characteristics, the degree of internal relations between technical characteristics, and the relationship between companies and customer expectations. Although objective, precise and exact numbers are used widely to represent linguistic evaluations, they do not give realistic results. Linguistic assessments are subjective and involve ambiguity. The use of fuzzy logic helps decision makers to eliminate problems arising from the subjective and ambiguous nature of information.

The company's crips and fuzzy final importance ratings are normalized to have a maximum uniformity degree and are shown in Table 8. In the crisp value, the value in each row is divided by the maximum value of the line, 0.014 (when the weight of the CR is not considered) and 0.005 (when the weight of the CR is considered). The fuzzy values are normalized by dividing the upper limit by 0.037 (when the weight of the CR is not taken into account) and 0.0028 (when considering the weight of the CR). ($\widehat{NW}_{Fs}$: The normalized importance ratings of companies)

**Table 8. Normalized and Fuzzy Values of Importance Ratings of Companies**

| *The weight of the CSC is not considered ($\widehat{NW}_{Fs}$)* | | | | *The weight of the CSC is considered ($\widehat{NW}^{*}_{Fs}$)* | | | |
|---|---|---|---|---|---|---|---|
| ***Crisp*** | ***L*** | ***M*** | ***U*** | ***Crips*** | ***L*** | ***M*** | ***U*** |
| 1,000 | 0,108 | 0,378 | 1,000 | 1,000 | 0,071 | 0,179 | 1,000 |
| 0,857 | 0,081 | 0,324 | 0,946 | 1,000 | 0,071 | 0,179 | 0,929 |
| 0,571 | 0,027 | 0,216 | 0,730 | 0,600 | 0,036 | 0,107 | 0,714 |
| 0,571 | 0,054 | 0,216 | 0,757 | 0,600 | 0,036 | 0,107 | 0,750 |
| 0,643 | 0,054 | 0,243 | 0,757 | 0,800 | 0,036 | 0,143 | 0,750 |
| 0,714 | 0,054 | 0,270 | 0,811 | 0,800 | 0,036 | 0,143 | 0,821 |
| 0,643 | 0,054 | 0,243 | 0,703 | 0,600 | 0,036 | 0,107 | 0,714 |
| 0,786 | 0,811 | 0,297 | 0,919 | 8,000 | 0,714 | 1,429 | 0,893 |

In table 8, although the crisp and fuzzy ratings have the same order in the order, crisp ratings are very close to the upper bounds of the corresponding fuzzy ratings and far away from the lower bounds. Fuzzy importance ratings better represent firms' importance changes. This will ensure that the industry is more flexible to capture and fulfill the needs for mineral water, so that firms' performances can be assessed in a more objective manner. The use of Quality Function Deployment has also enabled the conversion of customer needs for mineral water products to the technical characteristics of firms, as well as the relationships between them. Then, the effect of each company on each company selection criteria was researched and the final importance ratings of the company were found.

## CONCLUSIONS

It seems that there is intense competition among companies in the natural mineral water sector to increase their market share. In addition to price-driven competition, there is competition for product diversification. With the definition of processed mineral water in the regulations, transition to the production of fruit-flavored mineral waters, sold in 6 packages, use of non-recyclable packaging have contributed significantly to the development of the sector.

Under these conditions, the determination of the order of importance by the firms considering the customer expectations for the mineral water and the technical characteristics to realize these expectations helps the manufacturers to decide on the strategy determination and offers the opportunity to compare manufacturers' companies with their competitors. Even if the work is done in the natural mineral water sector, it is easy to adapt to the drinking water sector.

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