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The Methodology of Quality Function Deployment with Crisp and Fuzzy Approaches and an Application in the Turkish Shampoo Industry

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Abstract. This paper employs Quality Function Deployment (QFD) methodology to translate customer needs and requirements into the quality characteristics to improve quality for an existing product to develop a new consumer product.

The traditional quality function deployment technique consists of six steps. The purpose of the first step is to measure the voice of the customer that reveals his/her needs and wants using a questionnaire form and a face-to-face interview with sufficient number of customers to do an appropriate observation. The questionnaire is applied to both the observed firm and other competitor firms so as to figure out, through customers' competitive evaluation, the rate of importance of the customers' complaints. After determining necessary technical requirements by experts and employers with the brainstorming and other quality control tools, the fourth step provides the relationship between technical characteristics and customer needs. The following step points out the technical assessments. At the last step, quality planning is designed.

The study consists of two approaches to develop a new shampoo using quality function deployment technique. The first one is the crisp approach. In this approach, traditional QFD technique was employed to build a quality plan for a new shampoo. In the second stage of this study, fuzzy approach was used. This approach centered on the application of possibility theory and fuzzy arithmetic has been developed to address the ambiguity. At the final stage of the study, these two approaches have been compared with each other.

JEL Classification Codes : M29, D11, D12.

Key Words : Quality Function Deployment; Fuzzy Approaches.

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1. Introduction

It is a common notion that competition in industries is becoming increasingly intense. Given the trend of business globalization, companies face challenges from both national and international competitors. To counter this threat, many of them focus on searching for sustainable advantages. The survival of a company is heavily dependent on its capacity to identify new customer requirements and to develop a new product. (Shen, 2000)

New product development or improvement on existing one in today's technology–driven markets carries significant risks. Studies indicate that new product failure rates can be as low as one out of every three products. (Yelkur, 1996) It is one to actually discover and measure the customer's needs and wants but to achieve desired outcomes these findings need to be translated into company language. Therefore company should focus on what is wrong with the existing product or services and try to understand what the customer really wants. (Bouchereau, 2000)

QFD has been used as an important part of the product development process. QFD is an investment in people and information. It uses a cross functional team to determine customer requirements. QFD is a systematic and analytical technique for meeting customer expectation. QFD is a planning process for translating customer requirements (voice of the customer) into the appropriate technical requirements for each stage of product development and production (i.e. marketing strategies, planning, product design and engineering, prototype evaluation, production process development, production, sales) (Sullivan, 1986) and (Revelle, 1998).

The QFD concept is broken down into the two main activities: Product quality deployment and deployment of the quality function. Product quality deployment translates the "voice of the customer" into product control characteristics. Whereby, deployment of the quality function activities needed to assure that customer required quality is achieved. Deployment of the quality function examines the company response to the customer voice through an organized team approach (Khoo, 1996).

Yoji Akao introduced the concept of QFD in Japon in 1966. According to Akao QFD is a method for developing a design quality aimed at satisfying the consumer and then translating the consumer's demand into design targets and major quality assurance points to be used throughout the production phase (Edwin).

QFD is a method that is applied under the *kaizen philosophy* and within *total quality control management*. Some of benefits of QFD are summarized below (Bossert, 1991).

1. Customer Driven:
    a. Creates focus on customer requirements
    b. Uses competitive information effectively
    c. Prioritizes resources
    d. Identifies items that can be acted upon
    e. Structures resident experience/information

2. Reduces Implementation Time:
    a. Decreases midstream design changes
    b. Limits post-introduction problems
    c. Avoids future development redundancies
    d. Identifies future application opportunities
    e. Surfaces missing assumptions

3. Promotes Teamwork:
    a. Consensus based
    b. Creates communication at interfaces
    c. Identifies actions at interfaces
    d. Creates global view out of details

4. Provides Documentation:
    a. Documents rationale for design
    b. It is easy to assimilate
    c. Adds structure to the information
    d. Adapts to changes, a Living Document
    e. Provides framework for sensitivity analysis

QFD is a visual connective process that helps teams focus on the needs of the customers throughout the total development cycle. It provides the means for translating customer needs into appropriate technical requirements for each stage of a product development life cycle.

As it is mentioned above, QFD is performed by a multidisciplinary team representing marketing, design engineering, manufacturing engineering, and other functions considered critical by the company. In general, it provides a framework in which all participants can communicate their thoughts about a product. More specifically, QFD is often used to identify the relationships between requirements based on different viewpoints. There are two issues in analyzing these requirements using QFD. First, requirements are often described informally using vague terms and the analysis is performed on a rather subjective basis. Second, identifying relationships between requirements is often time consuming. Sometimes, it is difficult to arrive at a group consensus on a particular relationship between requirements. To overcome these difficulties related with QFD application, artificial intelligence techniques such as fuzzy logic and neural networks are proposed to resolve some of QFD' s drawbacks.

In this study, two approaches were used. In the first approach, the traditional QFD technique was used to develop and design a new shampoo. In the second approach, fuzzy logic was reviewed and incorporated within QFD. After finding quality characteristics to develop a new shampoo using traditional and fuzzy logic QFD method, these two results were compared with each other and interpreted.

2. First Approach: Traditional Quality Function Deployment

This study has employed QFD methodology for translating customer needs and requirements into the quality characteristics to design a new shampoo. To my knowledge, this is one of the few studies in the literature that employ the QFD technique to analyze the product development in the shampoo industry. Therefore for this study shampoo industry was chosen. QFD is also known as the house of the quality (HOQ). QFD uses a matrix format to capture a number of issues pertinent and vital to the planning process. The QFD matrix consists of six parts. The first step starts with constructing a list of product demands as voiced by the customer. The second part of the house of the quality is customers' competitive evaluations. The next step is to determine the quality characteristics. These quality characteristics, which are measurable, controllable that will impact on one or more customer demands. The forth phase is the correlation matrix to identify the interrelationship of each quality characteristic. The fifth step is an evaluation of the strength of the relationship between the customer demand and the technical requirements. The last step is the technical assessment. The output of the house of quality is not a product design but merely the requirements of the end product (Vonderembse, 1997). Figure1 denotes the principal components of the horizontal and vertical portions of the matrix (Day 1993).

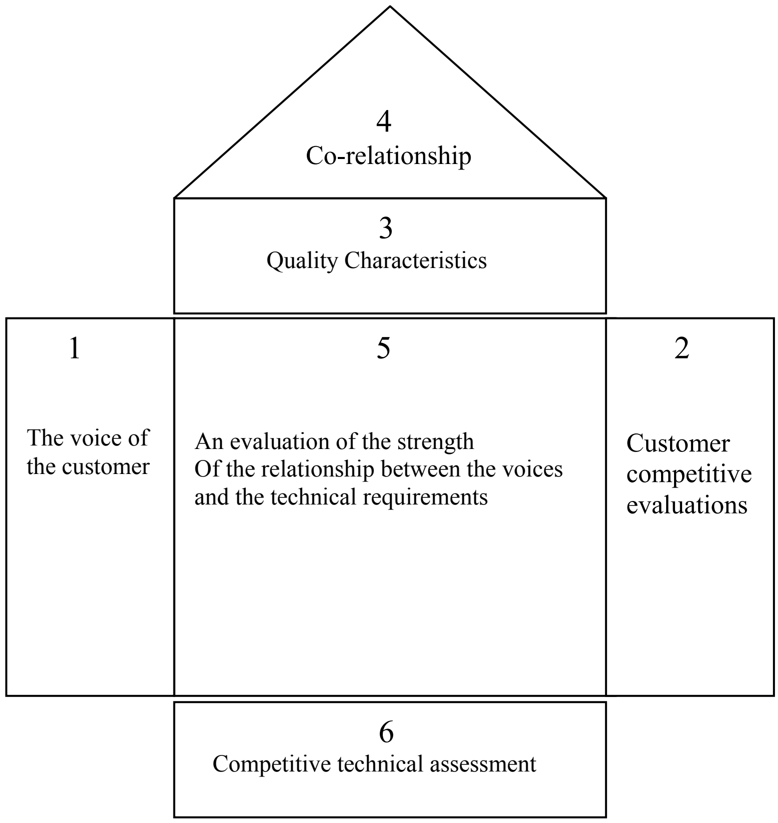

Figure 1

Stage 1: Determine the Customer Demands:

The initial and most critical step of the QFD process is the identification of what customers want and expect from a consumer product. In this step, customers' demands, expectations, and complaints are determined. Identified data contain current customer expectations that are critical to success and potential expectations that would excite customers. Several methods can be used to establish the customers' requirements, including: customer panels; focused group discussions; structured or unstructured customer interviews; self-completing questionnaires; in-depth customer observation; customers' complaint and compliment database; customers' service inquiries database; front-line staff feedback.

The list of customer demand was identified with literature search, and focusing on group brainstorming in the company, which was applied in this study. In the brainstorming process, group considered the complaints that were received from customer as an input. In addition that small customer group was chosen for the pilot study. In this study an open question was asked to the respondent to gather data. After collecting data, this list was obtained

The list of the customer demand is shown below:

1. Price
2. Brand
3. Fragrance
4. Vitamins
5. Naturalness
6. Prevents eye burn
7. Prevents dandruff
8. Softens hair
9. Provides brightness
10. Avoid hair loss
11. Easy to foam
12. Easy to rinse
13. Packaging
14. Ergonomic
15. Provides volume
16. Avoid stickiness
17. Appropriate for hair

At any one time it is unlikely that an organization can satisfy all of its customers' requirements. Therefore it is necessary to prioritize the needs that are to be met within a planning cycle systematically. Using a structured questionnaire, 240 customers were asked to rate the importance of the shampoo features identified and to compare the performance of the many shampoo with their “ideal shampoo” In this way it was possible to see which quality characteristics are more important for meeting or exceeding customers' expectations.

The *rate of importance* is a rating of the customer demands on a scale of 1 to 5. On this scale 5 denotes most important and 1 denotes relatively low importance. The customers should assign these ratings. Mean and standard deviation of the attributes is depicted in table 1.

Table 1: Mean and standard deviations of the attributes

Variables	Mean	Standard Deviations
Packaging	2,71	1,25
Price of shampoo	3,05	1,23
Prevents eye burn	3,09	1,36
Ergonomics	3,09	1,33
Brand of shampoo	3,70	1,20
Easy to foam	3,85	0,99
Fragrance of shampoo	3,90	1,06
Easy to rinse	3,96	1,02
To be natural	4,05	1,02
Vitamins	4,25	0,97
Prevents dandruff	4,25	1,05
Provides volume	4,25	0,99
Softens hair	4,33	0,92
Provides brightness	4,35	0,91
Appropriate for hair	4,50	0,64
Avoids stickiness	4,55	0,78
Avoids hair loss	4,63	0,81

In this case, considering mean value “Avoids hair lose” has the highest importance. “Avoids stickiness and Appropriate for hair” attributes were ranked the next priority. According to the table1, “packaging” had the lowest priority. However to be sure that whether or not all attributes are important, one needs an exploratory factor analysis.

Exploratory Factor Analysis: Exploratory factor analysis with varimax rotation was performed on the importance of attributes in order to extract the dimensions underlying the construct. The factor analysis of the 17 attributes yielded three factors explaining 62.8% of the total variance. Only twelve of the seventeen items loaded on these three factors and, based on the items loading on each factor, the factors were labeled *"Manageability factor”* (Factor 1), *“Maintenance factor”* (Factor 2), *“Cleanliness factor”* (Factor 3). These twelve items are shown as items in the Table 2. Therefore rest of the attributes was not considered. (Darrel 1999)

These items were factor analyzed to see if they were structurally related. Factor analysis is a multivariate technique, which links the six attributes in the factor1, and four attributes in the factor2, and two attributes in the factor3 in such a way that only the unique contribution of the twelve attributes is considered for each factor. Thus, using factor analysis avoids potential problems of multicollinearity.

The Cronbach's alpha measure of reliability for the three factors were; 0.80 for Factor 1, 0.79 for Factor 2, and 0.74 for Factor 3. All three values are above of the traditionally acceptable value of 0.70 in research (Raju, 1995).

Table 2: Factor Loading

Attributes	**Factor**		
	1	**2**	**3**
Provides brightness	0.800		
Provides volume	0.758		
Softens hair	0.657		
Fragrance of shampoo	0.572		
Avoids stickiness	0.567		
Prevents dandruff	0.548		
Naturalness		0.851	
Vitamins		0.747	
Appropriate for hair		0.703	
Avoids hair loss		0.632	
Easy to foam			0.817
Easy to rinse			0.803

Stage 2: Customer competitive evaluations

Customer competitive evaluation prepares a competitive or strategic assessment of the business. This plan brings out the firm's competitive weaknesses, strength and identifying areas needing quality improvement.

Customer competitive evaluation that is conducted according to the result of the survey is given in Table 3. This table consists of ten columns. Every column is explained below.

Column 1: At any one time it is unlikely that an organization can satisfy all of its customers' requirements. Therefore it is necessary to prioritize the needs that are to be met within a planning cycle systematically. Using a structured questionnaire, 240 customers were asked to rate the importance of the shampoo features identified and to compare the performance of the many shampoo with their "ideal shampoo" In this way it was possible to see which quality characteristics are more important for meeting or exceeding customers' expectations.

Column 2: This column represents the current performance of the product A considering the quality characteristics. The customer performance evaluation of the surveying company (product A) provides a listing of the satisfaction degree for the each of the quality characteristics. A scale of 1 to 5 was used.

Columns 3,4,5: The customer evaluation of the performance of the competitors' products of the surveying company was determined using a scale of 1 to 5. In this case three competitors were examined for comparing and benchmarking process.

Column 6: This column shows the planning phase of the company. This is determined by looking at where the consumer product is today, and what the competitors are doing with respect to the customer demands. It also takes into account the company's strategic plan and policy deployment.

Column 7: Column 7 contains the factor by which actual improvements must be adjusted to reach the levels that company A wants to achieve. These were calculated by dividing the planned quality target levels by the current quality levels. It is called the rate of improvement. The value of the rate of improvement 1.00 would signify that no improvement was necessary.

Column 8: This column that is named as sales point shows which customer demands or attributes of product have more important effect on marketing and image of the product. In other words which attributes of the product ensure competitive advantage for the company against its rivals. In this case the company can improve this competitive edge. In this study sales point scores were determined using brain storming process among the experts who works at the product development department in the company, which was applied this study.

A score of 1.5 is used to indicate a strong sales point. A score of 1.2 is used for a lesser sales point and a blank or 1.0 is used for items, which are not sales point.
It is impractical to make every customer demand a sales point. A weight, which was determined by experts can be assigned to the presence of a sales point and used in calculation of the quality weight (Omachonu, 1991).

Column 9: This column is named as row weight or absolute weight. Row weight is determined by multiplying the rate of importance (column 1) by the rate of improvement (column 7) and multiplying the result by the sales point (column 8).

$$\text{Row weight} = (\text{column } 1) \times (\text{column } 7) \times (\text{column } 8) \qquad (1)$$

Column 10: Final column is determined by converting the absolute weight to the percentage.

Stage 3: Determine the Technical Requirements

In this stage, determined customer demands were translated into technical requirements. The objective is to translate each customer voice into one or more technical requirements. Each technical requirement should be measurable and global in nature and should satisfy the voice of the customer (Radharamanan, 1996).

Stage 2 has addressed the “what” question by identifying customers’ requirements. This third stage addresses the “how” question by identifying the measurable and definable design features of the consumer product.

In this study, eight important quality characteristics, which were defined by Garvin, were considered to meet customer requirements. These are *performance, features, reliability, conformance, durability, serviceability, aesthetics, and perceived quality.* All of these quality characteristics were explained below (Rao, 1996):

Performance refers to the primary operating characteristics of the product or service. They are usually measurable. For a shampoo these characteristics would include the cleanliness factor such as, easy to foam or easy to rinse.

Table 3: Customer competitive evaluation matrix

Column No / Level of attributes		1	2	3	4	5	6	7	8	9	10
Primary Level	Secondary Level (Attributes)	Rate of Importance	Brand A	Competitor X	Competitor Y	Competitor Z	Goal	Improvement Ratio	Sales point	Row weight	Demand weight
Manageability Factor (1)	Provide brightness	4.34	3.59	3.2	3.52	3.14	4.34	1.21	1.5	7.87	10.37
	Provides Volume	4.25	3.36	3.24	3.17	2.85	4.25	1.26	1.2	6.45	8.50
	Softens hair	4.31	3.44	3.4	3.43	3.25	4.31	1.25	1.5	8.10	10.67
	Fragrance of shampoo	3.91	3.67	3.16	3.43	3.14	3.91	1.07	1	4.17	5.49
	Avoids stickiness	4.55	3.79	3.36	3.61	3.15	4.55	1.20	1.5	8.19	10.79
	Prevent dandruff	4.23	3.26	3.2	3.43	2.99	3.45	1.06	1.2	5.37	7.08
Maintenance factor (2)	Naturalness	4.05	3.21	3.16	2.83	2.81	4.05	1.26	1.2	6.13	8.08
	Vitamins	4.26	3.31	3.2	3.52	3.1	3.52	1.06	1	4.53	5.97
	Appropriate for hair	4.51	3.74	3.48	3.52	3.01	4.51	1.21	1.5	8.16	10.75
	Avoids hair loss	4.61	3.36	3.32	3.52	2.83	3.52	1.05	1.5	7.24	9.54
Cleanliness Factor (3)	Easy to foam	3.83	3.56	3.4	3.43	3.04	3.83	1.08	1	4.12	5.43
	Easy to rinse	3.95	3.36	3.12	3.39	2.96	3.95	1.18	1.2	5.57	7.34
										75.91	100.0

Table 4: Relationship matrix between hows and whats

Whats \ Hows		Performance	Features (formula)	Reliability	Conformance	Durability	Serviceability (promotion & advertisement)	Aesthetics
Primary Level	Secondary Level (Attributes)							
Manageability Factor (1)	Provides brightness	1	9	9	9	1	3	9
	Provides volume	1	9	9	9	3	3	9
	Softens hair	1	9	9	9	3	3	9
	Fragrance of shampoo		3	3	9	9	3	9
	Avoids stickiness	9	9	9	9		3	9
	Prevents dandruff	1	9	9	9	1	3	9
Maintenance Factor (3)	Naturalness	9	9	3	9	1	3	9
	Vitamins	3	9	3	9		1	1
	Appropriate for hair	3	9	9	9	1	3	3
	Avoids hair loss	9	9	3	9	1	3	3
Cleanliness Factor (2)	Easy to foam	9	9	9	9	3	3	
	Easy to rinse	9	9	9	9	3	3	
Weight of columns		457.40	867.15	725.61	900.09	191.05	288.09	615.66
		5	2	3	1	7	6	4

Features are additional characteristics that enhance the product/service appeal to the user. Adding conditioner to the shampoo can be given as an example; brightness for normal hair or extra vitamins is being added to feed hair.

Reliability of a product is the likelihood that a product will not fail within a specific time period. This is the key element for users who need the product to work without fail. An example is the mother who bathes her baby. She wants the baby shampoo not to hurt baby's eyes. Although Garvin states that reliability is more relevant to durable goods there are many examples of reliability as a key element of a service and fast moving product.

Conformance is precision with which the product or service meets the specified standards.

Durability measures the length of a product's life. For shampoo, it measures how long the shampoo will keep it's effectiveness of formula.
Serviceability is the speed with which the product can be put into service when it breaks down, as well as the competence and behaviour of the serviceperson.

Aesthetics is the subjective dimension indicating the kind of response a user has to a product. It represents the individual's personal preferences. It reflects the ways of individual's responds to the look, feel, sound, taste, and smell. A person judging the smell of a shampoo would say it is of higher quality but other can judge exactly opposite of this person.

Stage 4: Interrelationship between technical requirements

The roof of the house is designed to crosscorrelate the "hows" against each other so that design conflict and complementary characteristics can be identified. Many technical requirements are interrelated. Working to improve one requirement may help another related requirement and affect it in the positive way. On the other hand, working to improve one requirement may have a negative effect on the other requirement.

In the literature, usually co-relationship matrices show the use of four symbols. A double circle is used to indicate a strong positive co-relationship. A single circle is used to indicate a weak but positive relationship. Double X is denoted a strong negative relationship and a single X is denoted a negative relationship. To avoid complexity of four symbols, only two symbols will be used in this study. A circle shows a positive and an X shows a negative relationship between technical requirements (Shen, 2000).

In this study, positive relationship was found between features, reliability, conformance, and aesthetics.

Stage 5: Relationship matrix between hows and whats

After establishing the whats and hows, construction of house of quality continues with establishing the relationships between the customer voices and the technical requirements (Tan, 1998).

To build the relationship matrix between hows and whats, it is necessary to establish if relationships exist between every *what* and every *how*. All relationships are categorized such as either strong, medium, or weak. A score of 9 is used to indicate a strong relationship between whats and hows. A score of 3 signifies a moderate relationship and a square or 1 signifies a weak relationship between them. The matrix in Table 4 shows all relationship between customer requirements and technical requirements.

Stage 6: Column weights

Weights were calculated for each technical requirement that represent a combination of both the customers' level of importance and the strength of the relationships. This is accomplished by multiplying the relationship strength and the importance. Thus, in column 1, row 1, in Table 4, the customers' importance level (demand weight) is 10.37 and weight for the weak relationship is 1; their product is 10.37. At the intersection of column 1 and row 2, the product is 8.50. This calculation process is continued wherever there is a relationship in the column. For the column 1, the sum of these products is 457.40. Using the same calculation all of the column weights have been determined and shown at the bottom line of the Table 4.

Stage 7: Quality plan

After calculating column weights, it can be seen which particular technical requirements are important to improve first, so that effort could be concentrated on them for quality improvement study. In this case, *conformance* was determined to be the most important technical requirement. As it is explained earlier, conformance is defined as meeting the specified standards. For the fast moving consumer goods, consumer can have many alternative products for their preferences, therefore in order to satisfy the customer, company should meet at least required standards.

In the quality improvement plan, after meeting conformance of the product, *features* were found out to be the next important technical requirement. In the fast moving consumer products such as a shampoo, an extra attachment to the product compared to potential competitors' products is very critical for customer loyalty. The attachment that a consumer feels toward a product is shaped by two dimensions: the degree of preference and the degree of perceived product differentiation. Although customer has a strong preference about that product, if there is not a big difference between the product in concern and its competitors', customer can have many alternatives. In this situation, a strong preference combined with little perceived differentiation may lead a multi-product loyalty. Sometimes a consumer chooses a brand A, and other times, brand B. The customer can have a set of two or three favorites, and situational factors like shelf positioning and in-store promotions will drive that particular purchase. (Griffin, 1995)

The third important quality requirement is *reliability*. Like quality, reliability is often defined as in a similar "transcendent" manner a sense of trust in a product's ability to perform satisfactorily or resist failure. Formally reliability is defined as the probability that a product, piece of equipment, or system performs its intended function for a stated period of time under specified operating conditions. A reliability consideration during the process design is as important as product reliability during usage. Reliability engineers distinguish between inherent reliability, which is the predicted reliability determined by the design of the product or process, and the achieved reliability, which is the actual reliability observed during use. Actual reliability can be less than the inherent reliability due to the effects of the manufacturing process and the conditions of use. To be a reliable company, company should guide and manage the reliability expectation of the customer. High reliability can also provide a competitive advantage for many consumer goods. (Evans 1999)

The fourth important issue in the quality characteristics is the *aesthetics*. It is defined as the physical appearance of the goods and services. Advertisements, ads, promotions and communication methods have very strong affect on the physical appearance of the goods. (Moven, 2001)

After these quality characteristics have been improved, performance, serviceability, and durability should be improved respectively.

According to this approach, an evaluation of the strength of the relationship between demands of customer and technical requirements is based on ambiguous information. This is verbally described as strong, medium or weak. If the decision is strong, a score of 9 is used to indicate relationship between demand and quality characteristics. But sometimes it is not easy to make a certain decision about the relationship. If the decision makers do not have full knowledge to make a certain judgment, it can be difficult to make a decision whether if the relationship is strong or moderate. This type of ambiguity cannot be captured with the classical set theory based on crisp logic. Subjectivity is highly involved and plays a critical role in this decision-making. Therefore a fuzzy logic based approach can be more appropriate to evaluate the relationship between demand and quality characteristics. It captures the uncertainties involved and has been very effective in solving the multi criteria decision problems where data is ambiguous or defined in linguistic form.

3. The Second Approach: The Fuzzy Quality Function Deployment Approach

Various inputs, in the form of judgments and evaluations are needed in the QFD charts. Normally, these inputs are gathered through questionnaires, deep interviews, and focus groups. This gives rise to uncertainties when trying to quantify the information. Fuzzy logic can be used, in order to reduce the uncertainty of the collected data.

Fuzzy Logic: Fuzzy logic and fuzzy sets were introduced in 1965 by Professor L.A.Zadeh. Fuzzy logic uses human linguistics (word or sentences) understanding to express the knowledge of a system. This knowledge consists of facts, concepts, theories, procedures, and relationships and is expressed in the form of IF-THEN rules. Linguistic variables are characterized by ambiguity and multiplicity of meaning. Specifying good linguistic variables depends on the knowledge of the expert. For example "age" is a linguistic variable if its values are "young", "not so young", "old", and "very old". In fuzzy logic theory, a linguistic variable can be a member of more than one group. For instance, someone who is 27 years old belongs to both the "young" and "not so young" group at a different degree as can be seen in figure 2.

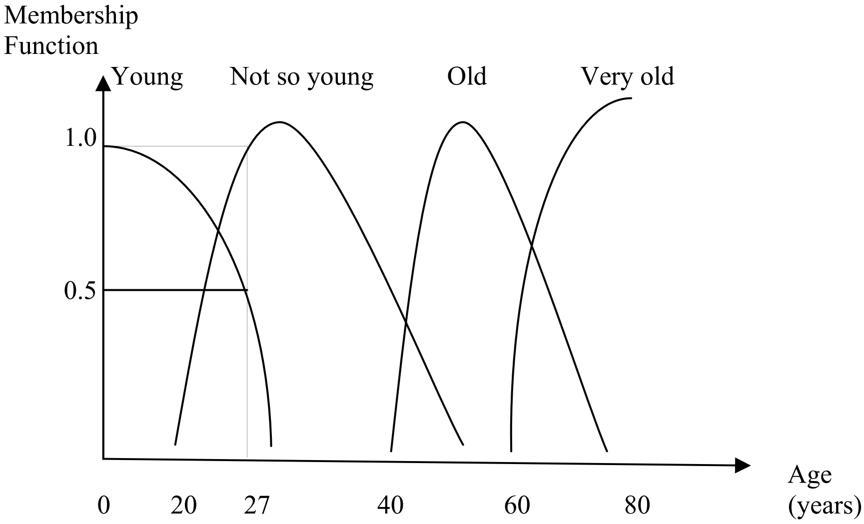

Figure 2

Fuzzy logic exhibits some useful features for exploitation in QFD. These include:

- It uses human linguistic to express the knowledge of the system
- It allows decision making with estimated values under incomplete or uncertain information.
- It is suitable for uncertain or appropriate reasoning.
- Interpretation of its rules is simple and easy to understand.
- It deals with multi input and multi output system.

Integrating Fuzzy Logic With QFD: In FQFD approach, crisp values are translated into fuzzy numbers, which can be considered as probability distribution (Zimmermann, 1986) used to test the significance of the coefficients. Mathematically,

$$A_{ij} = \lfloor \alpha_{1ij}, \alpha_{2ij} \rfloor \quad (2)$$

where A_{ij} is a symmetrical triangular fuzzy number (TFN) which is defined by the interval $[\alpha_{1ij}, \alpha_{2ij}]$. Using the same notation, a typical membership function for a symmetrical TFN, A_{ij}, can be expressed by;

$$\mu_{Aij}(a_{ij}) = 1 - \frac{\left| a_{ij} - \frac{\alpha_{2ij} - \alpha_{1ij}}{2} \right|}{\frac{\alpha_{2ij} - \alpha_{1ij}}{2}}, a_{ij} \in A_{ij} \tag{3}$$

The scalar multiplication of TFN and the sum of two symmetrical TFNs can be represented as follows (Kaufmann and Gupta 1985):

$$\lambda \circ [\alpha_1, \alpha_2] = [\lambda \cdot \alpha_1, \lambda \cdot \alpha_2] \tag{4}$$

$$[\alpha_1, \alpha_2] \circ [\beta_1, \beta_2] = [\alpha_1 \times \beta_1, \alpha_2 \times \beta_2] \tag{5}$$

Where λ denotes the scalar quantity and $[\alpha_1, \alpha_2]$ and $[\beta_1, \beta_2]$ are the intervals of the two symmetrical TFNs respectively.

In this study, individual rating equations can be generalized as:

$$\text{Individual rating} = \sum_j^n A_{ij} X_j \tag{6}$$

$$A_{ij} = \lfloor \alpha_{1ij}, \alpha_{2ij} \rfloor \tag{7}$$

Where A_{ij} and X_j denote the relative importance of the i^{th} characteristic with respect to the j^{th} customer need in the relationship matrix and importance of the j^{th} customer need perceived by the customer, which are customer rating respectively.

In this study, to compare between crisp individual ratings and fuzzy individual ratings, normalized individual ratings (Cole 1990) were used. The normalized individual rating for each characteristic can be determined as:

$$Normalized\ Individual\ Rating_i = \frac{Individual\ Rating_i}{Maximum\ Individual\ Rating} \qquad (8)$$

The relative importance and the customer rating can be linguistic or crisp variable. As mentioned, linguistic variables such as *strong relation,**(s)*** *moderate relation,**(m)*** and *weak relation,**(w)*** are used to describe the relative importance instead of 9, 3 and 1. These linguistic variables first translated into TFNs numbers (Table 5)

Table 5: Definition of linguistic variables

Linguistic variables	Fuzzy Number
Strong Relation (s)	[0.6-1.0]
Moderate Relation (m)	[0.3-0.7]
Weak Relation (w)	[0.0-0.4]

Table 6 shows customer rating and relative importance using linguistic variables. The ranges of linguistic values for quantifying the relationship were pre-determined by intuition. The ranges of ratings were then derived from calculated rating and pre-determined uncertainty value. In this study, uncertainty value was fixed ±0.1. For example *demand weight* was calculated at a score of 10.37 for *provide brightness attribute* in the traditional QFD approach. In the FQFD approach, demand weight was calculated as a range which is 10.27 – 10.47. For other attributes, demand weights were calculated in the same method and it is shown in the rating column in Table 6.

Using FQFD approach, individual ratings were calculated using equation (5) and (6). Then translated into normalized individual ratings by using equation (8).

Calculation Individual Ratings in Table 7 using FQFD Approach

a) *Performance Rating*

$\sum_{j}^{12} A_{1j} X_j =$ (10, 27x0,0; 10,37 x 0,4)+(8,4 x 0,0; 8,6 x 0,4)+(10,57 x 0,0; 10,77 x 0,4)+(5,39 x 0,0; 5,59 x 0,0)+(10,69 x 0,6; 10,89 x 1,0)+(6,98 x 0,0; 7,18 x 0,4)+(7,98 x 0,6; 8,18 x 1,0)+(5,87 x 0,3; 6,07 x 0,7)+(10,65 x

0,3; 10,85 x 0,7)+(9,44 x 0,6; 9,64 x 1,0)+(5,33 x 0,6; 5,53 x 1,0)+(7,24 x 0,6; 7,44 x 1,0)

= (31.59; 76.98)

All of the other ratings were calculated using the same notation above.

b) Feature rating

= (65.01; 98.99)

c) Reliability

= (48.81; 86.97)

d) Conformance

= (68.75; 101.81)

e) Durability

= (10,01; 63.49)

f) Serviceability

= (18.48; 79.61)

g) Aesthetics

= (45.95; 88.10)

Maximum Individual Rating=101, 81

Calculation Normalized Individual Ratings in Table 6 using FQFD Approach

Normalized Individual Rating for Performance:

= (31.59/101,81; 76.98/101,81) = (0.31;0. 76)

Normalized Individual Rating for Features:

= (65.01/101,81; 98.99/101,81) = (0.64;0. 97)

Normalized Individual Rating for Reliability

= (48.81/101,81; 86.97/101,81) = (0.48;0. 85)

Normalized Individual Rating for Conformance

= (68.75/101,81; 101.81/101,81) = (0.68; 1.00)

Table 6: Customer Ratings and Relative Importance Using Fuzzy Approach

	Rating	Performance	Feature	Reliability	Conformance	Durability	Serviceability	Aesthetics
Provides Brightness	10.27-10.47	w	s	s	s	w	m	s
Provides Volume	08.40-08.60	w	s	s	s	m	m	s
Softens hair	10.57-10.77	w	s	s	s	m	m	s
Fragrance of Shampoo	05.39-05.59		w	w	s	s	m	s
Avoids Stickiness	10.69-10.89	s	s	s	s		m	s
Prevents Dandruff	06.98-07.18	w	s	s	s	w	m	s
Naturalness	07.98-08.18	s	s	w	s	w	m	s
Vitamins	05.87-06.07	m	s	w	s		w	w
Appropriate for hair	10.65-10.85	m	s	s	s	w	m	m
Avoids Hair loss	09.44-09.64	s	s	w	s	w	m	m
Easy to foam	05.33-05.53	s	s	s	s	m	m	
Easy to Rinse	07.24-07.44	s	s	s	s	m	m	
Individual Rating		**31.59** **76.98**	**65.01** **98.99**	**48.81** **86.97**	**68.75** **101.81**	**10,01** **63.49**	**18.48** **79.61**	**45.95** **88.10**
Normalized Individual Rating		**0.31** **0.76**	**0.64** **0.97**	**0.48** **0.85**	**0.68** **1.00**	**0.10** **0.62**	**0.18** **0.78**	**0.45** **0.87**

Normalized Individual Rating for Durability

= (10,01/101,81; 63.49/101,81) = (0.10;0. 62)

Normalized Individual Rating for Serviceability

= (18.48/101,81; 79.61/101,81) = (0.18;0. 78)

Normalized Individual Rating for Aesthetics

= (45.95/101,81; 88.10/101,81) = (0.45;0. 87)

4.Result and Discussion

In this section, the results obtained were compared with those derived from the crisp approach and fuzzy approach tabulated in Table 7.

Table 7: Results generated by the FQFD approach and the crisp approach

Design Requirements	Fuzzy		Crisp
Performance	0,29	0,70	0,51
Feature	0,55	0,97	0,96
Reliability	0,42	0,83	0,81
Conformance	0,59	1,00	1,00
Durability	0,13	0,53	0,21
Serviceability	0,28	0,68	0,32
Aesthetics	0,42	0,83	0,68

The ratings related with the crisp approach are also normalized using the maximum ratings obtained. As it was mentioned before, normalized individual rating is calculated by dividing individual rating by the maximum rating. Maximum individual rating for the crisp approach is determined as a score of 900.09. This rating value shows that the conformance attribute has a maximum rating and the highest score. For each attribute of the shampoo normalized value is given below:

Calculation Normalized Individual Ratings in Table 7 using The Crisp Approach

Normalized Individual Rating for Performance:

= (457,40/900,09) = 0,51

Normalized Individual Rating for Features:

= (867,15/900,09) = 0,96

Normalized Individual Rating for Reliability

= (725,61/900,09) = 0,81

Normalized Individual Rating for Conformance

= (900,09/900,09) = 1,00

Normalized Individual Rating for Durability

= (191,05/900,09) = 0,21

Normalized Individual Rating for Serviceability

= (288,09/900,09) = 0,32

Normalized Individual Rating for Aesthetics

= (615, 66/900, 09) = 0, 68

The ratings related with the fuzzy approach were calculated before. As it is shown in table 8, the result obtained by both approaches exhibited an identical trend. It could be inferred that the feature and conformance were critical design requirement for the shampoo. However, the crisp approach tended to produce ratings that were close to the upper limits of the ranges registered by the FQFD. This might not be desirable as ratings were inflated through the normalization process and would possibly affect the selection of critical design requirements. The ratings generated in the FQFD approach, however, were expressed in terms of ranges of values. This would provide an overall picture about the design requirement concerned and could ensure that the decision made in the subsequent selection process would not be biased. As an example, the design requirement, *Aesthetics*, has a rating of 0.42-083. Qualitatively, this suggests that it is moderately important but far from being a critical requirement. However, a crisp rating of 0, 68 generated by the crisp approach may imply differently.

In the both approach, *conformance* was determined to be the most important technical requirement to produce a new shampoo. As it is mentioned before at the crisp approach, *features* were found out to be the second important technical requirement. If the fuzzy approach is considered, the range of the *features* was determined 0.55 – 0.97. The upper limit of the range is very close to maximum value of 1. Therefore it can be considered as an important requirement. At the crisp approach the third and forth-important quality requirements were determined reliability and aesthetics respectively. But at the fuzzy approach reliability and aesthetics has the same range. The range of the both is 0.42 – 0.83. Therefore reliability and aesthetics have the same importance considering fuzzy approach. Fifth and sixth important requirements were determined performance and serviceability respectively at the crisp approach. Performance has a score of 0.51 and serviceability has a score of 0.32. There is a big difference between these two values. But if the fuzzy approach is considered, the range of these two quality requirements has approximately the same that is 0.29 – 0.70 for performance and 0.28 – 0.69 for serviceability. Although there is a difference between these two requirements at the crisp approach, performance and serviceability has the same range at the fuzzy approach. The lowest important criterion is durability for both approaches.

5. Conclusion:

In this paper, we have studied how a quality plan can be determined for a shampoo product A by using QFD technique with a two different approaches. QFD links customer requirements or "whats" with the technical requirements or "hows" so the voice of the customer is translated into quality plan. Study was conducted in the six stages given above.

The first and the most important part of the study are to determine the customer wants and needs accurately. Seventeen customer demands were obtained using questionnaire. These customer demands were grouped under three factors, which were labeled as: Manageability factor, Maintenance factor, and Cleanliness factor. These three factors include only twelve attributes out of seventeen. Five attributes were eliminated because of low relationship with corresponding factors.

At the second stage of the study, brand A was evaluated with its three competitors. This evaluation was conducted by considering crisp and fuzzy approaches. According to the crisp approach, *avoids stickiness* in the manageability factor was found out the most important attribute to be improved. The second important attribute was determined in the maintenance factor that is *appropriate for hair*. The third one is *softens hair*, which is in the manageability factor. Manageability and maintenance factors are more important than cleanliness factor according to the customer evaluation. In the fuzzy approach, demand weights have been determined as a range rather than a crisp value. According to fuzzy approach, the range of ratings of the demands derived from calculated rating and pre-determined uncertainty value. In this study, uncertainty value was fixed ±0.1. Thus, *avoids stickiness* has a range of 10.69 – 10.89. It has the highest upper limit. *Appropriate for hair* has a range of 10.65 – 10.85. If these two customer demands are compared with each other it can be seen that there is a small difference between these two attributes. The next important customer demand is *softens hair*, which has a range of 10.57 – 10.77.

At the third step, these requirements were translated into the seven technical requirements. These characteristics, which were taken from Garvin's study, are performance, features, reliability, conformance, durability, serviceability, and aesthetics.

After determining relationship between hows and whats, the weights of each technical requirement were calculated. Considering this calculation, quality plan of shampoo A was determined. Conformance was found the first factor to be improved for both approaches. Then, in the crisp approach, features, reliability, and aesthetics were determined as essential technical requirements. Performance, serviceability and durability were found as the final improvement characteristics. On the other hand, in the fuzzy approach, result was slightly different than crisp approach. Conformance was also the most important attribute in the fuzzy approach, the features was ranked to be second factor affecting the consumer preference. Reliability and aesthetics have the same range, which is different in the crisp approach. After conformance and features, rest of the quality requirements have different priority in both approaches.

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