AN INTEGRATED APPROACH TO INNOVATIVE PRODUCT DEVELOPMENT USING FUZZY LOGIC, KANO MODEL AND QUALITY FUNCTION DEPLOYMENT

by

Çiğdem Çalışoğlu

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ABSTRACT

AN INTEGRATED APPROACH TO INNOVATIVE PRODUCT DEVELOPMENT USING FUZZY LOGIC, KANO MODEL AND QUALITY FUNCTION DEPLOYMENT

In today's competitive market, customer satisfaction is a key factor for the success of the companies. Quality fucntion depolyment (QFD) is a customer oriented approach that translates customer requirements into suitable technical requirements for each stage of product and service development. However, merely listening to the voice of customers (VOC) is not enough. Integration of Kano Model with QFD goes beyond the voice of customer and provides a better approach to achieve total customer satisfaction. Kano Model introduces innovative attributes which customers are unaware. However, the transformation functions used to adjust improvement ratio in traditional Kano-QFD models have some deficiencies. In addition, the calculation of the sales points of QFD by the companies themselves is a biased approach. This study presents two new approaches to optimize product quality by overcoming these deficiencies in the existing approaches: (i) Modified Kano-quality function deployment (MKQFD), and (ii) fuzzy kano-fuzzy QFD (FKFQFD). One of the main improvements of the first proposed model provides is the calculations of sales points according to the results of Kano Questionnaire (customer ratings). The second proposed model applies fuzzy logic to the MKQFD by representing sales points, importance of customer expectations, and relationships of engineering specifications and customer expectations, which are originally fuzzy statements, by fuzzy membership functions. An example is presented to illustrate the proposed approaches.

ÖZET

YENİLİKÇİ ÜRÜN TASARIMI GELİŞTİRMEDE BULANIK MANTIK, KANO MODELİ VE KALİTE FONKSİYONU YAYILIMININ BÜTÜNLEŞİK YAKLAŞIMI

Günümüz rekabet ortamında müşteri memnuniyeti, şirketlerin başarısı için büyük öneme sahiptir.Kalite fonksiyon yayılımı (KFY), ürün ve hizmet geliştirmenin her aşamasında uygulanabilecek şekilde müşteri gereksinimlerini teknik gereksinimlere dönüştürebilen, müşteri odaklı bir yaklaşımdır.Fakat bunun için müşterinin beklentileri dikkate almak yeterli değildir. Kano Modelinin KFY ile birleştirilmesi ise müşteri beklentilerinin dikkate alınmasının ötesine geçip tam müşteri memnuniyeti için daha uygun bir yaklaşım ortaya koyulmasını sağlar. Kano Modeli henüz müşterilerin dahi farkında olmadığı yenilikçi özelliklerin ortaya koyulmasını sağlar. Ancak, geleneksel Kano-KFY modellerinde geliştirme oranını belirlemek için kullanılan dönüşüm fonksiyonlarının birtakım eksiklikleri vardır. Bununla beraber, KFY'deki satış puanlarının şirketlerin kendileri tarafından hesaplanması taraflı bir yaklaşım olacaktır. Bu çalışma, varolan yaklaşımlarda bulunan eksikleri gidererek ürün kalitesini optimize etmek için iki yeni yaklaşım ortaya koymaktadır : (i) Değiştirilmiş Kano-kalite fonksiyon yayılımı (DKKFY) ve (ii) bulanık kano-bulanık KFY (BKBKFY). Önerilen ilk modelin geliştirdiği en önemli noktalardan birisi satış puanlarının Kano anketine (müşteri puanlamasına) göre yapılmasıdır. Önerilen ikinci model ise DKKFY'ye bulanık üyelik fonksiyonu sayesinde zaten bulanık ifadeler olan satış puanları, müşteri beklentilerinin önemi ve mühendislik tanımlamalarının müşteri beklentileri ile ilişkileri; ifadeleri üzerinden bulanık mantık uygulanmasıdır. Önerilen yaklaşımlar bir örnekle açıklanmıştır.

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DI	Dissatisfaction Index of product performance
f	Frequency of Kano cluster
k	Kano model category
m	Maximum of absolute values of Dissatisfaction Index or Satisfaction Index
p	Performance of the product
s	Satisfaction level of customer expectation
SI	Satisfaction Index
SP	Sales Point of Custemer expectation
w	Weight of Kano cluster
μ	Membership function of fuzzy set

LIST OF ACRONYMS/ABBREVIATIONS

A	Attractive Requirement
AHP	Analytical Hierarchy Process
ASI	American Supplier Institute
ASM	Active Shape Model
BKBKFY	Bulanık Kano- Bulanık Kalite Fonksiyon Yayılımı
BOM	Bill Of Material
CA	Customer Attributes
CEN	Eurpean Committee of Standardization
COG	Center of Gravity
DKKFY	Değiştirilmiş Kano-Kalite Fonksiyon Yayılımı
EC	Engineering Characteristics
FKFQFD	Fuzzy Kano-Fuzzy Qulity Functiom Deploymemt
FL	Fuzzy Logic
FLT	Fuzzy Logic Theory
FOM	First of Maxima
FST	Fuzzy Set Theory
H	High Importance
HOQ	House of Quality
I	Indifference Requirement
IR	Improvement Ratio
ISO	International Organization of Standardization
KFY	Kalite Fonksiyon Yayılımı
L	Low Importance
LOM	Last of Maxima
M	Must-Be Requirement
MI	Middle Importance
MF	Membership Function
MKQFD	Modified Kano-Quality Function Deployment

O	One Dimensioanal Requirement
PLM	Product Lifecycle Management
Q	Qestionable Requirement
QFD	Quality Function Deployment
R	Reverse Requirement
RSP	Receiver State Parameter
S	Strong Relationship
VH	Very High Importance
VL	Very Low Importance
VOC	Voice of The Customers
W	Week Relationship

1. INTRODUCTION

Quality is not a new concept in modern business, however especially in last decades it has become more and more important in every field of the industry. Quality in manufacturing systems, quality in personal lives, quality in services, quality in business support functions such as management, finance and accounting, human resource management, legal services etc. are seen as a first step to reach the success in any field. Also, rapid influx of a new technology and innovation, together with increased competition and globalization, has dramatically changed the nature of business process nowadays. To hold a market leadership today, a firm has to continually ask themselves of how to design and create high-quality products or services that may satisfy customers with the lowest possible cost in a timely fashion. Applying any of quality control tools such as Six Sigma, Quality Function Deployment (QFD), Taguchi Method, Kaizen, Poke-Yoke, Hoshin Planning Techniques etc. are possible answers of such desires [1].

One of the most widely accepted tools to take into account customer needs in the early design stages is the QFD approach. The success of the application is largely determined by the accuracy of the main input information, that is, the voice of the customers (VOC). In order to obtain accurate VOC, the use of Kano Model has been incorporated into QFD analysis by several researchers. A unique way of distinguishing the impact of different customer needs on total customer satisfaction in the early stage of products or services development is caught by Kano Model. Therefore, the risk factors of customer expectations about new product development or improvement on existing one in today's technology-driven market are decreased.

As mentioned in the beginning, quality studies are in every field. The competition in industries which is becoming intense and forces to launch new products in a very short span of time obliges to understand customer needs at the very beginning of design period and to manufacture the best product which can be done by using QFD and Kano model. One of the potential field is ergonomics which deals with human health, safety, performance and comfort. It uses the quality management tools very often for satisfying the customer expectations and protecting their health at the same time.

1.1. Quality Function Deployment (QFD)

Quality Function Deployment (QFD) is a customer-driven planning process to guide the design, manufacturing, and marketing of goods. It is an overall concept that provides a means of translating customer requirements into appropriate technical requirements for each stage of product development and production [2, 3]. One of its founders Dr Yoji Akao, defined the concept as follows:

> QFD provides specific methods for guaranteeing quality at each stage of the product development process, starting with design. In other words, it is a method for introducing quality right from design stage to satisfy the customer and to transform customer requirements into design objectives and key points that will be required to ensure quality at production stage.

1.1.1. Applications of QFD in the Literature

QFD is a very popular quality approach that helps to understand customer expectation. Thus, many examples in various fields can be easily found during the literature survey. Some of researchers prefer to use just QFD for improving the quality of products or services. Also, some of the use it with other quality tools in order to enhance the effects of the QFD. Due to thousands of studies about QFD, just a few ones are listed in Table 1.1 in order to show how many different fields used QFD and how many other tools could be used with QFD.

Table 1.1. Research studies and conceptual papers on the QFD [1, 4–18].

Authors	**Application Field**	**Additional Quality Approaches**
Min Hua Lu, Christian N. Madu, Chu-Hua Kuel and Dena Winokur (1994)	Strategic Marketting	Analytical Hierarchy Process (AHP)
William D. Barnett and M. K. Raja (1995)	Software Development	-
H. Jagdev, P. Bradley, O. Molley (1997)	Performance Improvement Tool	-
Kai Yang, Kailash C. Kapur (1997)	Customer Reliability	Robust Design
Ming Zhao (1998)	Mixed Integer Programming	Fuzzy Logic and Optimization Model
K. F. Puns, K. S. Chin and Henry Lau (2001)	Service Optimization	Hoshin Planning Techniques
K.C Tan, Theresia A. Pawitra (2001)	Tourism	Kano Model and Servqual
Yi Qing Yan, Shou Qing Wang, Mohammad Dulaimi, Sui Pheng Low (2003)	Construction Industry	Fuzzy Logic
Tomohiko Sakp, Kentaro Watanabe, Yoshiki Shimomura (2003)	Environmental Problems	Receiver State Parameter(RSP) based Service Model
Fa'bio Lui's Ramos da Silva, Katia Lucchesi Cavalca (2004)	Sport Bicycles	Value Analysis Tool

Table 1.1. Research studies and conceptual papers on the QFD (cont.)

Authors	**Application Field**	**Additional Quality Approaches**
X. Lai, M. Xie, K. C. Tan (2004)	Product Design	Kano Model
David Ginn, Mohammed Zairi (2005)	Automotive Sector	-
Yesim Sireli, Paul Kauffmann,Erol Ozan (2007)	Cockpit Weather Information System Design	Kano Model
Xin Lai, Kay-Chaun Tan, Min Xie (2007)	Product Design	-
H. Raharjo A.C. Brombacher, Bon Bergman (2010)	Design for Six Sigma	Kano Model
Yu-Cheng Lee, Liang-Chyau Sheu, Yuan-Gan Tsou (2008)	PLM Systems	Fuzzy Theory, Kano Model

1.1.2. History of Quality Function Deployment (QFD)

QFD originated in Japan in 1966 by Professors Shigeru Mizuno and Yoji Akao and was first introduced at the Kiyotaka Oshiumi of Bridgestone Tire in Japan around 1966. The purpose of Professor Mizuno and Akoa was to develop a quality assurance method that would design customer satisfaction into a product before it was manufactured. Akoa published the idea as a system in an April 1972 magazine article under the name Hinshitsu Tenkai System which means a system of quality deployment [19].

Very reputable companies used this quality approach in order to enhance their success. The company of Kiyotaka Oshiumi of Bridgestone Tire presented the first large scale application with the help of fishbone diagram to indentify each customer requirement and to identify the design substitute quality characteristics and process controls. In 1972, with the application of QFD to design of an oil tanker at the Kobe Shipyards of Mitsubishi Heavy Industry, the fishbone diagram became useless due to unwieldy growing, thus the fishbone diagram was changed into a matrix format named as quality table with the rows being desired customer expectations and column being the technical specifications of controlling and measurable causes. Then, in 1979 Toyota Auto Body had developed a quality table that had a "roof" on top and then changed the term of quality table into quality house due to its similar shape. This change was passed on through the American Supplier Institute (ASI) as the House of Quality (HOQ) [19, 20].

QFD was formally introduced to the United States and Europe in 1983 when the American Society for Quality Control published Akaos's work in Quality Process and Cambridge Research (today named as Kaizen Institute) invited Akao to give a QFD seminar in Chicago. In 1987, Bob King published a book, Better Design in Half the Time: Implementing QFD in America. Soon later, John Hauser and Don Clausing's article, The House of Quality, was published in the May-June 1988 edition of the Harward Business Review [19].

Since those publications were written, QFD has become more and more popular and has being used in every field of science and industry. Besides the manufacturing companies such as Ford, General Motors, Chrysler, Polaroid, Proctor & Gamble, DuPont, General Electric etc, different science disciplines such as ergonomics, health care, product design etc have introduced this quality approach into their studies to get continuous quality improvement.

Although the QFD methodology is widely used, Quality Function Deployment does not immediately give an easy understanding of what the methodology is or does. It originated from Japanese phrase consisting of three characters, each of which has several meanings:

- Hin shitsu: It means “quality”, “features”, “attributes” or “qualities”
- Kino: It means “functions” or “mechanisms”
- Ten Kai: It means “deployment”, “evaluation”, “diffusion” or “development”

Basically, QFD means deploying the attributes of a product or service expected from customers throughout all the appropriate functional components of an organization. More formally, QFD is an overall concept that provides a means of translating the customer requirements and desires into the technical specifications or requirements for each stage of product development and production [19, 21].

QFD is an interdisciplinary team process to plan and design new or improved products or services in a way that:

(i) Focuses on customer expectations.
(ii) Prioritize design goals by using potential competitive environment and marketing.
(iii) Uses and strengthens inter-functional teamwork.
(iv) Introduces right products and services to market faster and shorter design periods by translating customer requirements into measurable goals [20, 21].

The QFD methodology consists of a structured multiple matrix driven process to:

(i) Customer requirements planning matrix: Translate customer requirements into engineering or design requirements.
(ii) Product characteristic deployment matrix: Translate engineering or design requirements into product or part characteristics.
(iii) Process plan and quality control charts: Translate product or part characteristics into manufacturing operations.
(iv) Operating instructions: Translate manufacturing operations into specific opera-

tions and control points [20,21].

1.1.3. A Process of Quality Function Deployment

Beginning of the QFD is to understand the customer expectations about the product or service that is tried to be improved. Once a product plan which defines the target market and customers is established, the next step is to plan how do capture the customers' needs for each development project which includes identifying and contacting potential customers, selecting true mechanisms to collect true information or desires from them. These customer requirements are most often referred as the Voice of Customer (VOC) due to establishing the lists by customer's own words. Listening the VOC can help QFD practitioners capture customers' desires [2,20].

A set of matrices is used to translate the VOC to product's or service's technical requirements, then to component requirements, then to process control plans, and then to manufacturing operating, respectively. Each result is used as an input for the next matrix. Very first and the most widely recognized matrix is the HOQ which provides translating the customer expectations into engineering or design specifications. The output of this operation is to get a list of technical specification according to their significance. Then, in the next operation the engineering or design requirements according to the previous process are translated into the product or part characteristics. Likewise the HOQ result, this second operation gives importance of product or part characters that will be used in the third procedure, translating product or part characteristics into manufacturing operations. And lastly, in the final matrix specific operations and control points are determined. The schematic representation can be seen in the Figure 1.1. The operations are told as product planning, part planning, process planning, production / operation planning, respectively.

The main matrix in QFD is HOQ which includes customer's needs with their own words. HOQ that is the most recognized form of QFD that serves completely the purpose of QFD, understanding the customer expectation for launching the products or services to the market with higher quality.

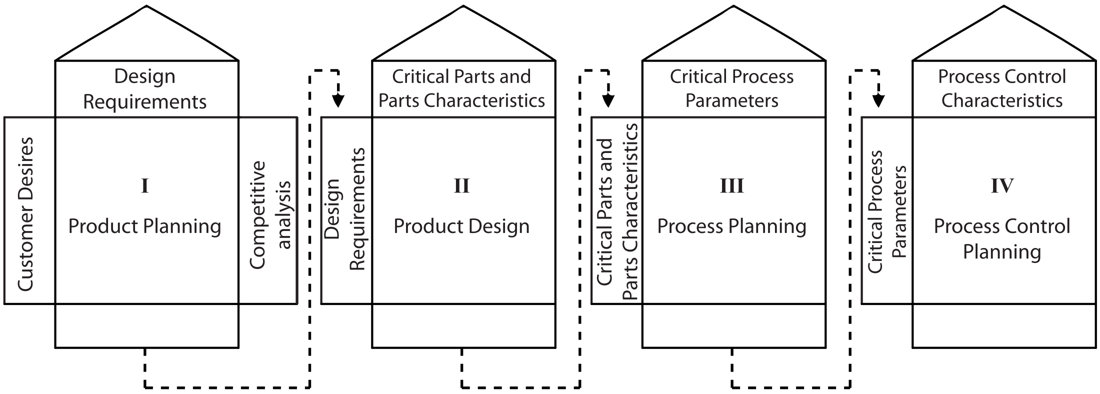

Figure 1.1. The QFD process.

Building the HOQ starts with the question: what do customers want? Mostly this question is answered by collecting the information by market researches which can include many different ways such as one by one interviews, or focus group meetings, or questionnaires etc. The results are then used to develop a hierarchy of importance for the product technical requirements [20].

As its name suggests, the QFD approach is based on deploying user expectations, that is also told as "What lists", in terms of production-related parameters, also named as "How lists", for the new product or improved product. The philosophy of establishing the What lists and How lists at different phases of product development is the principal of the implementation of QFD, where what lists are recorded on rows and how lists are recorded on column in a matrix structure [22].

After the requirements are identified, quantitative market research is conducted to evaluate the positions of the competitors in the market in term of customer satisfaction. Based on the comparing of different brands, the positions of each customer expectation are seen clearly and the targets for customer satisfaction for all are set. Targets help the designers to determine which technical specification is more important than the other by constructing correlated matrix of customer requirements and design attributes [23]. A schematic summary of each step in HOQ and template of the HOQ are shown Figure

1.2 and Table 1.2 repectively.

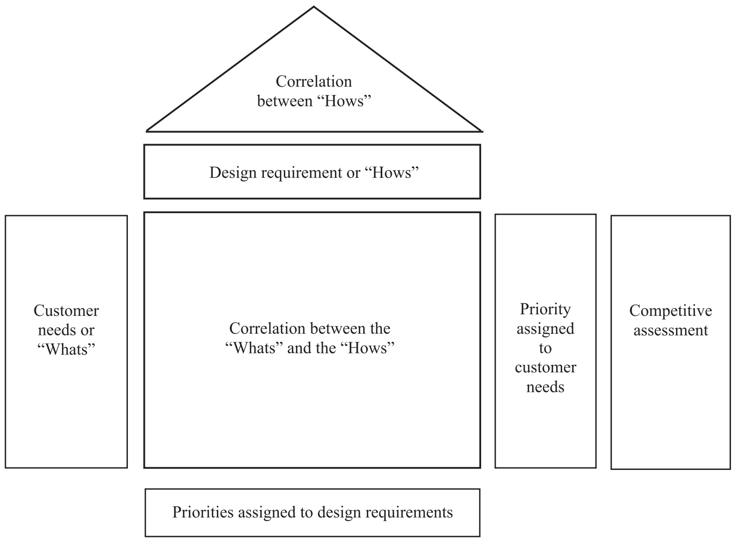

Figure 1.2. The HOQ matrix.

1.1.3.1. Identifying Customer Needs. The backbone of the QFD is the VOC. However, before finding the customer needs or expectations, the question, "who is the customer?" should be answered. Many times this is not an easy task. Who is affected by the product? Is it the final user or the purchaser? For the purchasers, the key word is cost whereas for the final user, most of time, satisfaction becomes more crucial than other criteria. Therefore, the answers orientate the designers to wrong direction if the right customer were not determined [21].

One of the main problems to identify the customer needs is contents of the questions. In order to get right information about the specific product or service, customer should not be faced with biased questions which stops final user to express their true feelings about the product or service. Biased questions just provide the designers to get what they want to be heard while answers of pure and unbiased questions reflect the real customer expectations.

Another problem is to decide how much detail is needed while collecting the data

Table 1.2. The HOQ template.

	HOW LIST/ENGINEERING SPECIFICATIONS					IMPORTANCE	OUR PRODUCT TODAY	COMPETITOR 1	COMPETITOR 2	OUR PRODUCT FUTURE	IMPROVEMENT RATIO	SALES POINT	ABSOLUTE WEIGHT	RELATIVE WEIGHT
WHAT LIST /CUSTOMER SPECIFICATIONS														
ABSOLUTE WEIGHT														
RELATIVE WEIGHT														

and verbatim. Too many detail and unnecessary information sometimes leads to the designers to skip the main purpose. For example, if collecting and categorizing the main data creates a 2000 cell matrices, many people will be discouraged from finishing the matrix and then will stop the study. QFD should be at most a macro level of detail which, then, should be broken into smaller QFD's at a micro subsystem level of detail [20]. If many small HOQ are built, design team could be subdivided into smaller units in order to keep all HOQ under the control.

<u>1.1.3.2. List the Product Requirements Necessary to Meet Customer Needs.</u> Product requirements or how lists are design characteristics that describe the customer requirements as expressed in the language of the designer and engineers. Essentially, technical specifications are the how lists by which the company will respond to the customer needs namely what lists. The distinctive feature of this list when comparing with what lists is that they are not formed by open-ended sentences like customers expressions. They must be measurable, since the output is controlled and compared to objective target [2].

<u>1.1.3.3. Customer Competitive Analysis.</u> This step is done to identify weights of each customer requirement according to market comparison and evaluation of importance

ranking of existing products or services for each. Competitive evaluations are performed for discovering weaknesses and strengths points of the company in terms of customer satisfaction. Knowing the strengths and weaknesses in the ability of the competitors to meet the consumer needs provides to get advantage for becoming a leader in the market. Companies may change their strategies or may overview their design parameters according to competitor analysis [19].

Every comparison is done to understand the difference between own product and other products in the market and finally to determine future level target for all customer requirements. As shown in the Table 1.2, competitor analyses are located on columns of the left part of the HOQ. There are nine columns in this part that should be filled.

(i) First column: Importance of the each customer requirements which is identified by designer teams is listed. 1 to 5 rating where 1 states very low importance and 5 states vey high importance is used [3].

(ii) Second column: Current customer satisfaction level for each requirement is stated in the second column. 1 to 5 rating, where 1 means very low satisfaction and 5 designates very high satisfaction, is utilized [3].

(iii) Third column and fourth column: These columns are reserved for the comparison of competitors. Same rating system used on first two columns is used in here. Market surveys, customer meetings or focus groups are suggested to obtain feedbacks about the competitors' products [2].

(iv) Fifth column: In here, future target of customer satisfaction is listed.

(v) Sixth column: An improvement ratio is stated in this column. It is computed by dividing the future goal rating by current rating [3].

$$\text{improvement ratio (IR)} = \frac{\text{(future goal)}}{\text{(current customer satisfaction level)}} \tag{1.1}$$

(vi) Seventh column: This column is labeled as "Sales point" column. It shows which customer demand or attribute of the product have more important effect on marketing for the company. In other words it denotes which attributes of the product ensure competitive advantage for the company against its rivals. In literatures, sales points is mostly rated as

- 1.0 assigning status quo which means no additional sales advantage
- 1.2 denoting a moderate sales point and
- 1.5 indicating a strong or significant sales advantage [2, 3]

(vii) Eight column and ninth column: After completing the quantification of previous seven column, a customer score is computed for each customer expectations by multiplying importance, improvement ratio and sales point. Results which will be used later as weighting customer requirements yield a hierarchy of customer needs based on designer team's assessment on the three variables. On the ninth column relative importance of each requirement is calculated [2, 3].

$$\text{absolute score}_i = (\text{importance}_i \times \text{improvement ratio}_i \times \text{sales point}_i) \tag{1.2}$$

$$\text{relative score}_i = \frac{\text{score}_i}{\max(\text{absolute score})} \tag{1.3}$$

where i indicate each of customer needs and n shows total number of customer requirements.

<u>1.1.3.4. Relationship Matrix between Customer Needs and Engineering Specifications.</u>

Customer requirements are listed one under the other on the left side of HOQ, while technical requirements are written side by side on the top locations of HOQ. The degree of relationship between customer attributes and engineering specifications are determined in this stage and noted on this matrix. The purpose of the relationship matrix is to show whether the final technical requirements adequately address the customer requirements. The assessment is usually based on expert experience, designer knowledge, customer responses and controlled experiments if they were done [2].

In the literature, generally three types of relationship are defined.

(i) Weak relationship: In this kind of relationship, changes in engineering specifications are not in direct relationship with customer expectations. For example, price of cell phone has weak relationship with battery of the cell phone. Type or capacity of battery has not much effect on price.

(ii) Moderate relationship: In this kind of relationship, technical specifications have direct affect on the customer expectations. For example, price of cell phone increase or decrease the properties of memory size or camera resolution of the cell phone, therefore, these engineering specifications have moderate relationship.

(iii) Strong relationship: In this kind of relationship, customer expectations have very strong relation with engineering properties. For example, price of cell phones are determined mostly according to screen resolutions and variety of applications in the phone. Thus, they have strong relationships.

The lack of a strong relationship between customer requirements and any technical specification shows that either the customer needs are not addressed or the final product will have some difficulties in meeting the customer expectations. Similarly, if a technical requirement does not affect any customer needs, it may be redundant or some significant customer expectations may be forgotten [2].

<u>1.1.3.5. Interrelationship of All Technical Specifications.</u> The roof of the HOQ shows the interrelationship among the all engineering specifications. In this part, both positive and negative relationships are tried to be determined. In literature, some authors are used strong positive relationship, positive relationship, negative relationship and strong negative relationship. Some of them are just used positive and negative relationships. And some of them also used positive moderate and negative moderate relationships. But in the end, all of them try to find the answers of one type of question such as "How does a change of one product characteristic affect others?" and assess of trade-offs between characteristics [21, 24].

<u>1.1.3.6. Prioritization of Technical Requirements.</u> Relative weights for the design attributes are calculated based on the strength of the correlation between design specifica-

tions and customer needs and on the relative importance of the customer requirements. Benchmarking also has an important role at this point. The results of comparison indicate whether or not evaluations of both customer satisfaction and technical requirements satisfaction are consistent with each other. If a competing product is found to best satisfy a customer requirement but the evaluation of the related technical specifications indicates otherwise, then either the measurement processes are wrong or the product has a different image on customer (either positive sympathy toward the competitor or negative approaches toward the company's product or service) which affects customer perceptions [20–24].

1.1.3.7. Determinining Which Technical Requirement Is Applied First. In this stage, the absolute and relative weights of all technical specifications are interpreted in order to determine which design decision are needed to made based on customer expectations. These characteristics will need to be clearly identified so that proper action can be taken in the design stage and production process to assure that customer needs are met [2,21]. If n customer requirements and m technical specification exist, then absolute and relative weights of all m engineering specification are found as:

$$\text{absolute weight}_z = \sum_{i=1}^{n} \text{relative weight of customer atribute}_i \times \text{relationship}_{iz} \quad (1.4)$$

where $i = 1, 2, \ldots, n$ and $z = 1, 2, \ldots, m$.

$$\text{relative weight}_z = \frac{\text{absolute weight}_z}{max(\text{absolute weight})} \quad (1.5)$$

1.2. Kano Model: The Theory of Attractive Quality

Kano model was introduced as a a methodology for assessing the different quality elements which were categorized according to degree of customer satisfaction. In [25] it is stated that Kano model is based on the two-factor of satisfaction. In the article, they suggested that the factors causing satisfaction are different from factors causing dissatisfaction. Therefore, to achieve total customer satisfaction in an economic way, designers should not only know what customers want most, but also understand how much attention should be paid to each requirement to achieve the desire customer satisfaction level. In other words, now level of the customer satisfaction and dissatisfaction about each attributes becomes a parameter for the designers [25, 26].

In many quality managements tools such as QFD, engineers assume that customer know all features about the product or services and expect to make judgment about them acocording to customers' previous experiences. However, customers are usually not able to accurately specify the desired product attributes in the real world. Especially, results and feelings about new innovative changes cannot be interpreted accurately by customers. The Kano Model Theory provides to identify the core of customer requirements and their importance according to the categories of different satisfaction levels. The requirements are classified into these clusters by the functional and dysfunctional questions about all customer expectations. Explanation of what these questions are and how they are asked to the customers will be found in the Kano Model Questionnaire part (Section 1.2.4).

1.2.1. Applications of Kano Model Theory in the Literature

The innovative product development process requires understanding continuously changing customer expectations and needs. Kano Model Approaches, which is generally accepted by many author provides a methodology to achieve this and has been used in a number of studies in variety of fields (Table 1.3). This procedure can help a company or project team to gain a profound knowledge of customer expectations and satisfactions, and then help to develop products with innovative features [4].

Table 1.3. Research studies and conceptual papers on the Kano Model Theory [10, 18, 25, 27–31].

Authors	**Application Field**	**Additional Quality Approaches**
Quanli Xu, Roger J. Jiano, Xi Yang, Martin Helander (2009)	Automotive Design	-
K.C Tan, Theresia A. Pawitra (2001)	Tourism	QFD and Servqual
Gül Bayraktaroğlu, Özge Özgen (2007)	Library Services	Analytical Hierarchy Process (AHP)
Yu-Cheng Lee (2008)	Product Lifecycle Management	-
Elif Kılıç Delice, Zülal Güngör (2008)	Classification of Customer Expectations	-
X. Lai, X. Xie and K. C. Tan (2004)	Product Design	QFD
Dong-Han Ham, J. Heo, P. Fossick, W. Wong, S. Park, C. Song, M. Bradley (2007)	Mobile Phone	-
Jeongyun Heo, Sanhyun Park, Chiwon Song (2007)	Human-Computer Interaction	-
Hendry Raharjo (2007)	Design for Six Sigma	QFD
Yesim Sireli, Paul Kauffmann,Erol Ozan (2007)	Cockpit Weather Information System Design	QFD

1.2.2. Kano Classification

The Kano Model Theory is a useful tool to classify and prioritize customer needs based on how they affect customer satisfaction. Opposite to QFD approaches, this theory explains the relationships between product performance and customer satisfaction as a nonlinear functions as shown in Figure 1.3. The theory of attractive quality (Kano model theory) proposes six classes of customer requirements according to customer satisfaction level.

(i) Must-be requirements (or basic quality elements) (M):Features included in this group are thought as basic criteria of products. Therefore, if they are not fulfilled, the customer will be extremely dissatisfied and will not be interested in the product at all. On the other hand, in the opposite situation, the fulfillment of the must-be requirements cannot provide a particular satisfaction for the customers. In other words, the increasing the performance of these attributes provides diminishing returns in term of customer satisfaction [32]. This nonlinear relationship is shown in the Figure 1.3. For example, having poor brakes in a car causes high customer dissatisfaction, however, having good brakes does not increase customer satisfaction or customer attention on that product.

(ii) One-dimensional requirements (performance requirements) (O): Previous assumption about the relationship between product performance and customer satisfaction is seen in this type of requirements. In other words, as for those requirements, satisfaction is proportional to the performance level. They result in customer satisfaction when they are fulfilled whereas result in dissatisfaction when they are not fulfilled. For example, better gas mileage in a car provides proportional customer satisfaction, and worse gas mileage causes dissatisfaction [1,32]. Generally, the price for which customers are willing to pay for product is closely tied to performance requirements. The linearity can be seen in Figure 1.3.

(iii) Attractive requirements (excitement attributes) (A): This types of customer requirements are unexpected or unspoken by customers but can result in high levels of customers satisfaction, however, the absence of them does not lead any dissatisfaction because customers are mostly unaware of what they are missing. They mostly include new innovative changes which make people very excited about the new technology. In a competitive market where different companies' products show similar performance, innovative improvements providing by attractive attributes provide a competitive advantage. Figure 1.3 shows nonlinear relationship between changes in satisfaction level and increment in attractive requirements. For instance, automobile customers may not be dissatisfied if seats are not heated when needed but the customers may be more satisfied when the cars have heated seats [33].

(iv) Indifference requirements (I): The category means that the customer is not much interested in this type of features, whether it is present or not. In other words, quality elements that result in neither satisfaction nor dissatisfaction, whether they are fulfilled or not [26, 32]. Car color, for instance, is not a significant concern during the car purchasing, thus this attribute can be said as indifference requirement.

(v) Reverse requirements (R): They are thought as quality elements which result in dissatisfaction when they are fulfilled and in satisfaction when they are not fulfilled [26], Therefore, not only they are desired by customers but also the reverse of them are expected.

(vi) Questionable requirements (Q): This type of class indicated that either the questions were asked incorrectly or the customers misunderstood them or illogical responses were given. For example, if functional and dysfunctional questions about less fuel consumption expectations are asked to the customers and both "I like it that way" answers are given, then this customer requirement is clustered as questionable attribute.

By using the Kano Model, the design team can enhance the understanding of customer needs and leading to superior product design.

1.2.3. Determination of Customer Satisfaction Level in Kano Model

In many quality approaches like QFD, it is assumed that level of customer satisfaction is increased when the performance of product features are increased. And

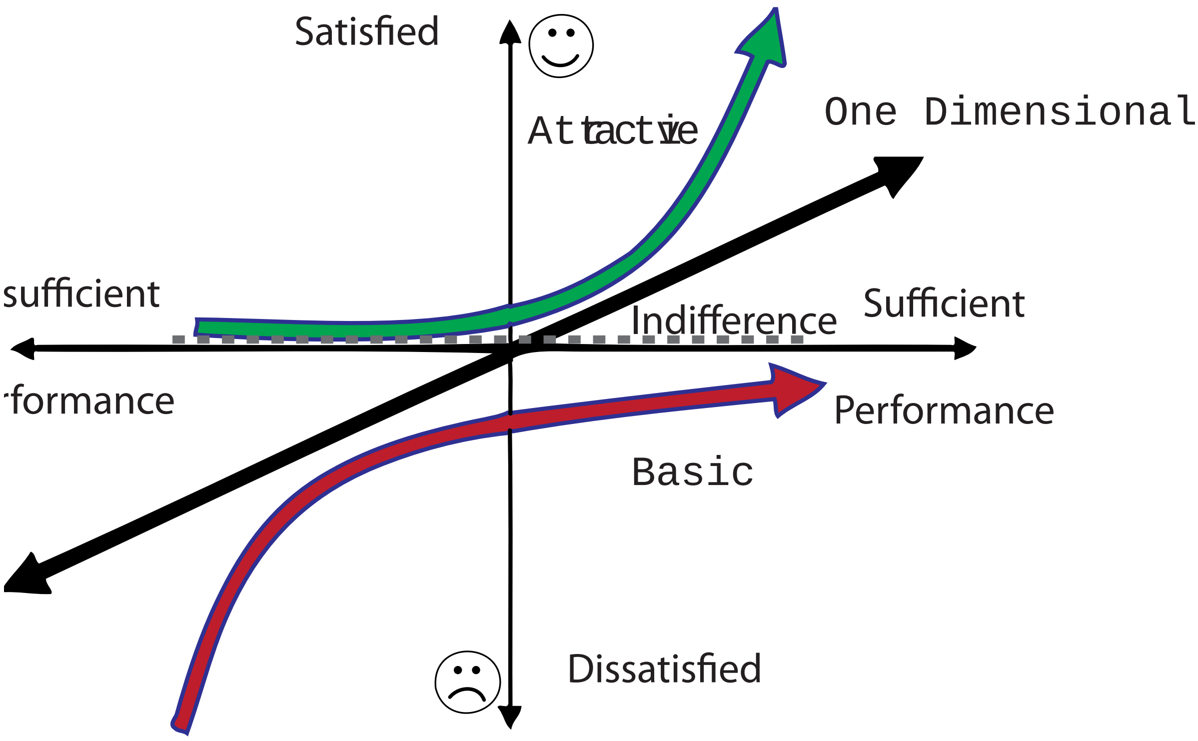

Figure 1.3. Kano Model: Theory of Attractive Quality [25].

like one-dimensional attributes, their relationship function is generally thought as linear opposite to functions shown on Figure 1.3. Kano model emphasizes that not all customer attributes have the same relationship trend with customer satisfaction level and thus the assumption about linearity is not accepted. Basically, according to Kano Model, change in satisfaction level depends on both change in product performance and category of customer requirements. This relationship can be generalized as a function as follows:

$$s = f(k, p) \tag{1.6}$$

where s indicates satisfaction level, p shows performance of the product and k indicates Kano model category. For one-dimensional requirements, linear relationship between change in customer satisfaction and change in product performance can be express as

$$\frac{\Delta s}{s} = \frac{\Delta p}{p} \tag{1.7}$$

where Δs and Δp indicate a small shift of s and p, respectively. For must-be requirements, the expressions becomes as follows

$$\frac{\Delta s}{s} < \frac{\Delta p}{p}. \tag{1.8}$$

On the other hand, attractive quality elements provide high satisfaction level increments. Therefore, the equality changes as follows

$$\frac{\Delta s}{s} > \frac{\Delta p}{p}. \tag{1.9}$$

According to the equation 1.6, by using the parameter k, above three relationship formulae can be expressed by one equation

$$\frac{\Delta s}{s} = k\frac{\Delta p}{p}. \tag{1.10}$$

For attractive attributes k is larger than 1, for one-dimensional attributes k equals to 1 and for must-be attributes k is between 0 and 1, for indifference attributes k is 0.Here, other two clusters, reverse and questionable requirements, are not represented by Kano model index, because they do not give any information about customer satisfaction level and product performance. Reverse requirements show that the requirements should be examined in the opposite way and questionable requirements indicate that the Kano questionnaire about those requirements was asked in a wrong way.

Which requirement is included into which category is found by Kano questionnaire which are interpreted by Kano evaluation table. Explanations of Kano questionnaire and Kano evaluation table are on the next parts.

1.2.4. Kano Questionnaire

Kano Model explains that for some customer attributes, customer satisfaction is dramatically increased with only a small improvement in performance whereas for other customer requirements, small amount increase is gained even when the product performance is greatly improved [1]. Therefore, for designers and engineers, the first step is to learn customer expectations and needs and then, to find which requirement is belonging to which category. It can be found by Kano Questionnaire which is done by two separate market of research.

1.2.4.1. First Market Research. This research is done to provide market awareness before starting design stage. By marketing research activities such as telephone surveys, mail-back surveys, questionnaires, the awareness of customers about the product features and their expectations can be easily learned. Gathering customer expectations and then analyzing and interpreting the surveys provide to compose a map for designers about the design stages. However, the importance of the customer expectations and satisfaction levels provided by fulfillment of them are not evaluated by this first customer survey.

1.2.4.2. Second Market Research. A second market research is then done after preparing a Kano questionnaire, which is based on results of first market survey, in order to understand the real significance and priority of customer needs. Moreover, at the end of the first survey, only information depends on customers' past experiences can be learned and interpreted. By asking the Kano questionnaire opinions of the customers about existence properties and new innovative changes can be learned.

The Kano questionnaire can help the designers and engineers to classify the requirements according to six categories like must-be, one-dimensional, attractive, indifference, reverse or questionable attributes. For each requirements, a pair of questions is formulated to which the customer have five choices to answer. The first question is about the reaction when the product or service can fulfill the requirement, whereas the second one is about the reaction when the product or service cannot fulfill the requirement. Usually, the five choices are, "I like it that way", "it must be that way", "I am neutral", "I can live with it that way" and "I dislike it" [16]. An example is show in Table 1.4. Questions are named as functional and dysfunctional form of the questions, respectively.

Table 1.4. Kano model questionnaire: (1) functional question and (2) dysfunctional question.

Questions	**Possible Responses**
1. If the kettle is shut down automatically after boiling, how do you feel?	1. I like it that way 2. It must be that way 3. I am neutral 4. I can live with it that way 5. I dislike it that way
2. If the kettle is not shut down automatically after boiling, how do you feel?	1. I like it that way 2. It must be that way 3. I am neutral 4. I can live with it that way 5. I dislike it that way

For each customer requirements, customers will be asked to answer functional and dysfunctional questions explained above. By combining the two answers, the customer requirements can be classified into different categories. How answers are combined and evaluated is explained in the next part.

1.2.5. Kano Evaluation Table

Once all the Kano questionnaires for a survey have been collected, designers tabulates them by looking up the classification of each customer needs in the Kano evaluation table which is shown at Table 1.5.

If the customer answers, for example, “I like it that way” for corresponding question of functional question, “if the kettle is shut down automatically after boiling, how do you feel?” and answers “it must be that way” or “I am neutral” or “I can live with it that way” for corresponding dysfunctional question, “if the kettle is not shut down automatically after boiling, how do you feel?”, the combination of the results in the evaluation table produces category A, indicating that shutting down automatically is an attractive attribute from the customer point of view. If the combining answers yield I, this means that customer is indifferent to this product feature. Likewise, if the answers designates category O, it means that requirement is one-dimensional requirement for consumers. Also, M indicates the must-be attributes. R means reversible attribute. Category Q stands for questionable results. Questionable scores signify that the question was phrased incorrectly or the person interviewed misunderstood the questions and answered that wrongly [27, 34].

1.2.6. A Classification of Product Requirement by Kano Model Approach

In the following part, it will be explained how product requirements can be classified by means of a questionnaire.

Table 1.5. Kano evaluation table [3].

Product requirement		Dysfunctional question				
		I like it that way	It must be that way	I am neutral	I can live it that way	I dislike it that way
Functional question	I like it that way	Q	A	A	A	O
	It must be that way	R	I	I	I	M
	I am neutral	R	I	I	I	M
	I can live it that way	R	I	I	I	M
	I dislike it that way	R	R	R	R	Q

- Step 1 - identifying customer requirements: The starting point for constructing the Kano questionnaires is to learn the product requirements which have been determined by detail market survey. Focus groups, telephone surveys, mail-back surveys etc can be used for reaching the end users and understanding their expectations.
- Step 2 – construction of the Kano questionnaires: Must-be, one-dimensional, attractive, indifference as well as reverse and questionable attributes are classified by Kano questionnaires. For all requirements, positive and negative types of questions, named as functional and dysfunctional respectively, are prepared for the questionnaire.
- Step 3 – Evaluation of Kano Questionnaire: By combining the pair of questions for each requirements and using Kano evaluation table, the classification of each attributes is done.
- Step 4 – Determination of Priority Requirements: After evaluating all answers, designers or engineers should prioritize customer needs according to purpose of

the product. A competitive product or service should meet must-be attributes in order to respond customers' basic expectations, also should maximize the one-dimensional attributes for increasing customer satisfaction and should include as many attractive attributes as possible to provide differentiation when comparing with competitors.

1.3. Fuzzy Logic Theory

The concept of Fuzzy Logic (FL), which is a form of many-valued logic and deals with the reasoning based on approximation rather than exact truths, was conceived by Lotfi Zadeh, a professor at the University of California at Berkeley it 1965 [35]. It began with a proposal of a fuzzy set theory (FST) which presents people the acceptance of uncertainty. The simple question of how it is possible has again a very simple answer. In contrast to traditional logic theory which has an absolute true or false result represented by binary variables, 1 and 0, fuzzy logic variables have truth value that ranges from 0 to 1 by the help of FST. A fuzzy set is a set of object in which there is no clear-cut or predefined boundary between objects that are or are not member of a set [35]. In other words, now there is no more crisp set membership or non-membership. Instead, there is a partial set membership.

In dealing with a decision process, the decision maker is often faced with doubts, problems and uncertainties. Most of the time, words are the rescuers of peoples to explain those doubts and inaccuracies which is not expressed by numeric terms and variables sufficiently. A fuzzy logic uses human linguistics (words or sentences) to express knowledge of system. According to [36], the knowledge of anything consists of facts, theories, concepts, procedures and relationships and is expressed in the form of If-Then rules. Specifying good linguistic variables depends on the knowledge of the experts. 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 is member of more than one groups, however the degree of membership is different for each of them. For example 27 year-old belongs to both "young" and "not so young" groups at the same time with different degree of membership as can be seen in Figure 1.4 [36].

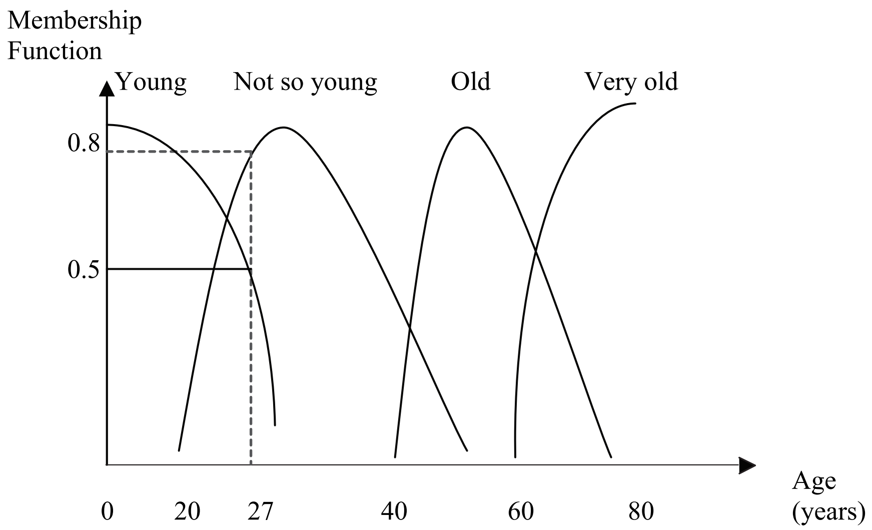

Figure 1.4. An example of Fuzzy Sets.

For better understanding, a small example can be given about the comparison of fuzzy logic and traditional logic. In traditional logic theory, assumptions are either true or false, therefore there is no a third alternative. For instance, If there is a universe X which includes all positive integers and if there is a assumption about x in X which is "integers larger than 2", then every answers is either 0 or 1. However, in fuzzy logic theory, assumptions are based on mostly subjective decisions like previous example about age which leads to obtain more than one results with different membership grades. In traditional logic theory, if cluster A includes the true results of any assumption $p(x)$, the complement of A is written as A' which contains the wrong results of assumption $p(x)$. Then, the universe cluster and intersection cluster can be written as in Equations 1.11 and 1.12, respectively [37].

$$A \cup A' = E \tag{1.11}$$

$$A \cap A' = \emptyset. \tag{1.12}$$

1.3.1. Fuzzy Logic Applications in the Literature

FL, which deals with all approximations rather than exact results, is used in many applications that range from process control to medical diagnosis. It may be viewed as an extension of multi-valued logic. Therefore, many studies in various fields were found during the literature survey. Some of them are listed in Table 1.6, which shows authors and application area, and additional quality approaches used if any.

Table 1.6. Research studies and conceptual papers on the Fuzzy Logic Theory [9, 11, 35, 38–47].

Authors	**Application Field**	**Additional Quality Approaches**
Zoran Salcic	Traffic Control in ATM Network	-
Emre Kıyak, Ayşe Kahvecioğlu (2003)	Flight Control Problem	-
Hao-Tien Liu, Nai-Chieh Wei	Product Design	QFD
Lotfi A. Zadeh (1996)	Product Design	-
S. Vinodh, Suresh Kumar Chintha (2011)	Lean Manufacturing	QFD
Cengiz Kahraman, Selçuk Çebi (2009)	Hierarchical Fuzzy Axiomatic Design	AHP, Axiomatic Design
M. C. Lin, C. Y. Tsai, C. C. Cheng, C. A. Chang (2004)	Low-end Digital Camera Design	QFD
Chuen Chien Lee (1990)	Control Systems	Axiomatic Design
M. R. Zahedi, S. Yousefi, M. Cheshmberah (1992)	Enterprise Resource Planning Software	QFD
Metin Çelik, Selçuk Çebi, Cengiz Kahraman (2009)	Routing of Shipping Investment Decision	QFD

Table 1.6. Research studies and conceptual papers on the Fuzzy Logic Theory (cont.)

Authors	**Application Field**	**Additional Quality Approaches**
Selçuk Çebi, Cengiz Kahraman (2010)	Group Decision Support Seystem	-
R. T. Moghaddam, S. H. Amin, G. Zhang	Location Selection	QFD
Lofti A. Zadeh (1975)	Approximate Reasoning	-
Selim Zaim, Mehmet Şevketli	Turkish Shampoo Industry	QFD
Yi Q.Yang, S. Q. Wang, M. Dulaimi, Su P. Low (2003)	Buildable Design Decision Making	QFD
Ming Zhou (1998)	Product Development	QFD

1.3.2. Theoretical Background of Fuzzy Logic Theory

Nowadays operation researches make the analyses to solve decision making problems, however most of time the results are not deterministic. Therefore, mathematical models using binary variables are not enough to cover practical situations. To deal with the uncertainty, fuzzy set theory (FST) as mentioned before is recommended [40, 47].

The fuzzy inference system is based on the concept of the fuzzy set theory, fuzzy If-Then rules, and fuzzy reasoning. The basic fuzzy inference system consists of three basic conceptual components:

(i) "a rule base", which contains a selection of the fuzzy rules,

(ii) "a data base" (or dictionary), which defines the membership functions used in the fuzzy rules,

(iii) Uses and strengthens inter-functional teamwork.

(iv) "a reasoning mechanism", which performs inference procedure upon the rules and given facts to drive reasonable output or conclusion [48].

If X is a collection of objects denoted by generally x, then a "fuzzy set" in X is defined as a set of ordered pairs:

$$A = \{(x, \mu_{\mathrm{A}}) \,|x \in X\} \tag{1.13}$$

where μ_{A} is called a membership function (MF) for the fuzzy set A. The MF maps each of the elements in X to a membership grade between 0 and 1. It is obvious that, this definition is the generalization of the fuzzy sets, therefore there is no a strict rule that the universe X is continuous. Consequently, a fuzzy set A in X may be represented as a set of ordered pairs of generic element x and its grade of MF, $\mu_{\mathrm{A}}\,(x)$. When X is continuous, a fuzzy set A is written as:

$$A = \int_X \frac{\mu_{\mathrm{A}}(x)}{x}. \tag{1.14}$$

When X is discrete, a fuzzy set A is represented by:

$$A = \sum_{i=1}^{n} \frac{\mu_{\mathrm{A}}(x_i)}{x_i}. \tag{1.15}$$

A fuzzy set is uniquely specified by its MF. In order to understand MF deeply, some nomenclatures should be defined.

1.3.2.1. Support of Fuzzy Set. A support of fuzzy set A is the set of all points x in X such that $\mu_{\mathrm{A}}(x) > 0$.

$$\text{support}(A) = \{x|\mu_{\mathrm{A}}(x) > 0\}. \tag{1.16}$$

1.3.2.2. Core of Fuzzy Set. A core of fuzzy set A is the set of all points x in X such that $\mu_{\mathrm{A}}(x) = 1$.

$$\text{core}(A) = \{x|\mu_{\mathrm{A}}(x) = 1\}. \tag{1.17}$$

1.3.2.3. Normality. A fuzzy set A is normal if its core is nonempty. In other words, if a point x such that $\mu_{\mathrm{A}}(x) = 1$ can always be found, then the fuzzy set A can be said as a normal.

1.3.2.4. Crossover Points of Fuzzy Set. A crossover point of fuzzy set A is the set of point x in X such that $\mu_{\mathrm{A}}(x) = 0.5$.

$$\text{crossover}(A) = \{x|\mu_{\mathrm{A}}(x) = 0.5\}. \tag{1.18}$$

1.3.2.5. Fuzzy Singleton. A fuzzy set whose support is a single point in X with $\mu_{\mathrm{A}}(x) = 1$ is called fuzzy singleton.

1.3.2.6. α-Cut and Strong α-Cut. The α-cut or α-level set of a fuzzy set A is a crisp set defined by:

$$A_{\alpha} = \{x|\mu_{\mathrm{A}}(x) \geq \alpha\}. \tag{1.19}$$

The strong α-cut or strong α-level set of a fuzzy set A is defined similarly with small changes:

$$A'_\alpha = \{x|\mu_{\mathrm{A}}(x) > \alpha\}\,. \tag{1.20}$$

Using the notation of a level set, the support and core of fuzzy set A can be expressed as in equations 1.21 and 1.22 ,respectively.

$$\mathrm{support}(A) = A'_0 \tag{1.21}$$

$$\mathrm{core}(A) = A_1. \tag{1.22}$$

1.3.2.7. Fuzzy Set Operations. Before introducing the ordinary fuzzy set operations, union, intersection and complement, the notion of containment which plays a central role in both ordinary and fuzzy sets, should be explained.

A fuzzy set A is contained in fuzzy set B (or equivalently, A is subset of B) if and only if $\mu_{\mathrm{A}}(x) \leq \mu_{\mathrm{B}}(x)$ for all x.

$$A \subseteq B \Leftrightarrow \mu_{\mathrm{A}}(x) \leq \mu_B(x). \tag{1.23}$$

(i) Operation of union: The union of two fuzzy set A and B is concluded as a fuzzy set C, written as $C = A \cup B$ or $C = A$ OR B. Mathematically,

$$\begin{aligned}\mu_C(x) &= max\,(\mu_{\mathrm{A}}(x), \mu_S(x)) \\ &= \mu_{\mathrm{A}}(x) \vee \mu_S(x).\end{aligned} \tag{1.24}$$

(ii) Operation of intersection: the intersection of two fuzzy set A and B is concluded as a new fuzzy set C, written as $C = A \cap B$ or $C = A$ AND B. Mathematically,

$$\mu_C(x) = min\,(\mu_{\mathrm{A}}(x), \mu_S(x)) \qquad (1.25)$$
$$= \mu_{\mathrm{A}}(x) \wedge \mu_S(x).$$

(iii) Complement of Fuzzy Set: A complement of a fuzzy set A, is denoted by $A(A, \overline{A})$, is defined as:

$$\mu_{\overline{A}}(x) = 1 - \mu_{\mathrm{A}}(x). \qquad (1.26)$$

1.3.2.8. Types of Membership Functions (MF). Fuzzy sets are completely characterized by the MFs. The most convenient way to define the MF is to express it as a mathematical formula. Most popular MFs can be listed as:

(i) Triangular MFs: A triangular MF is specified by three parameters (a, b, and c) as follows:

$$y = \text{triangle}(x; a, b, c) = \begin{cases} 0 & x \leq a \\ \frac{x-a}{b-a} & a \leq x \leq b \\ \frac{c-x}{c-b} & b \leq x \leq c \\ 0 & c \leq x \end{cases}. \qquad (1.27)$$

The parameters $\{a, b, c\}$, where $a < b < c$, determine the x coordinates of three corners of the underlying triangle MF [48]. Figure 1.5 illustrates a triangular MF defined by triangle $(x; 5, 15, 35)$.

(ii) Trapezoidal MFs: The trapezoidal MFs are specified by four parameters $\{a, b, c, d\}$

as follows:

$$y = \text{trapezoid}(x; a, b, c, d) = \begin{cases} 0 & x \leq a \\ \frac{x-a}{b-a} & a \leq x \leq b \\ 1 & b \leq x \leq c \\ \frac{c-x}{c-b} & c \leq x \leq d \\ 0 & d \leq x \end{cases}. \tag{1.28}$$

The parameters $\{a, b, c, d\}$, where $a < b \leq c < d$, determine the x coordinates of four corners of the underlying trapezoid MF [48]. Figure 1.6 illustrates a trapezoidal MF defined by trapezoid $(x; 10, 20, 40, 75)$.

(iii) Gaussian MFs: A Gaussian MF is specified by two parameters (c, α). Mathematically,

$$y = \text{gaussian}(x; c, \alpha) = e^{-\frac{(x-c)^2}{2\alpha^2}}. \tag{1.29}$$

where c and α are the center and width of the fuzzy set A, respectively [48]. Figure 1.7 shows an example of Gaussian MF defined by gaussian $(x; 50; 20)$.

1.3.3. Linguistic Variables and Fuzzy Rules

A basic concept in fuzzy logic that plays a key role in many of its application is linguistic variables which, as its name suggests, is a variable whose values are words or sentences in a nature or synthetic language. For example, “age” is a linguistic variable if its values are “young”, “not so young”, “old” and “very old” [40, 47].

In general, the values of a linguistic variable can be generated from a primary term like “young”, its antonym as “old”, a collection of modifiers such as “very”, “not”, “more or less”, “quite” etc. and the connectives like “and” and “or”. Furthermore, each value of linguistic variable is represented by a probability distribution as shown in Figure 1.7 for variable “age”. When, linguistic variable such as “age” is used, the underlying base variable “age” is numerical in nature. Thus, in this case, meaning of

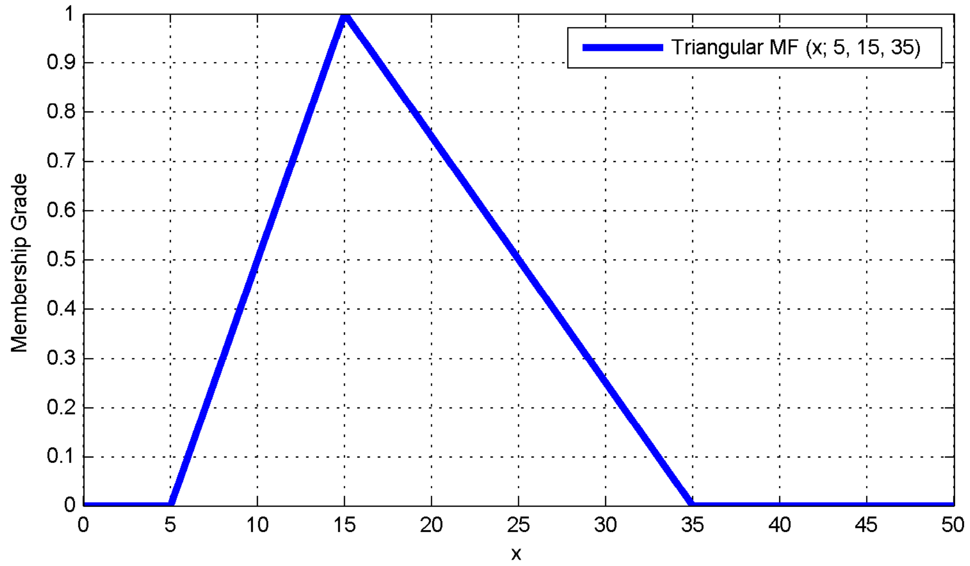

Figure 1.5. Example of triangular MF.

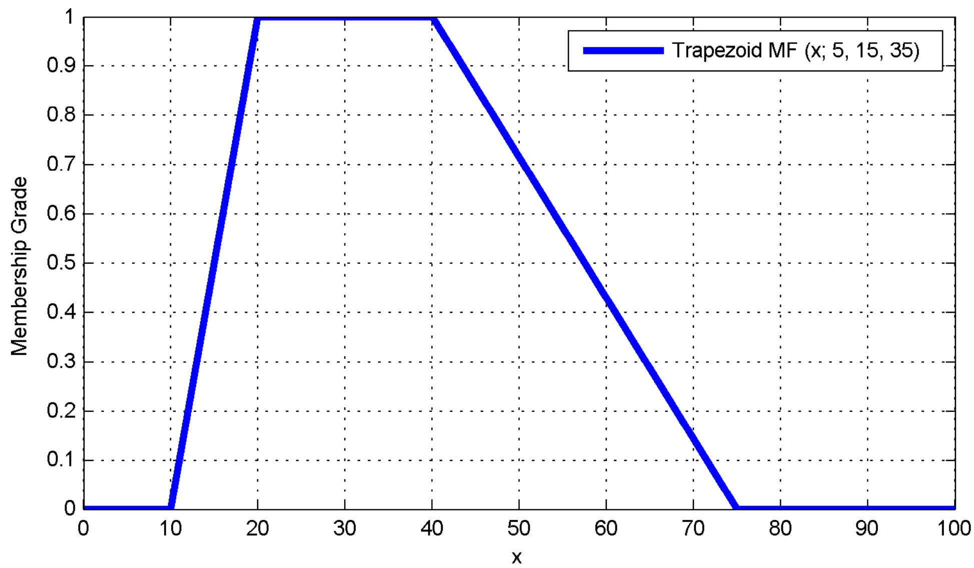

Figure 1.6. Example of trapezoid MF.

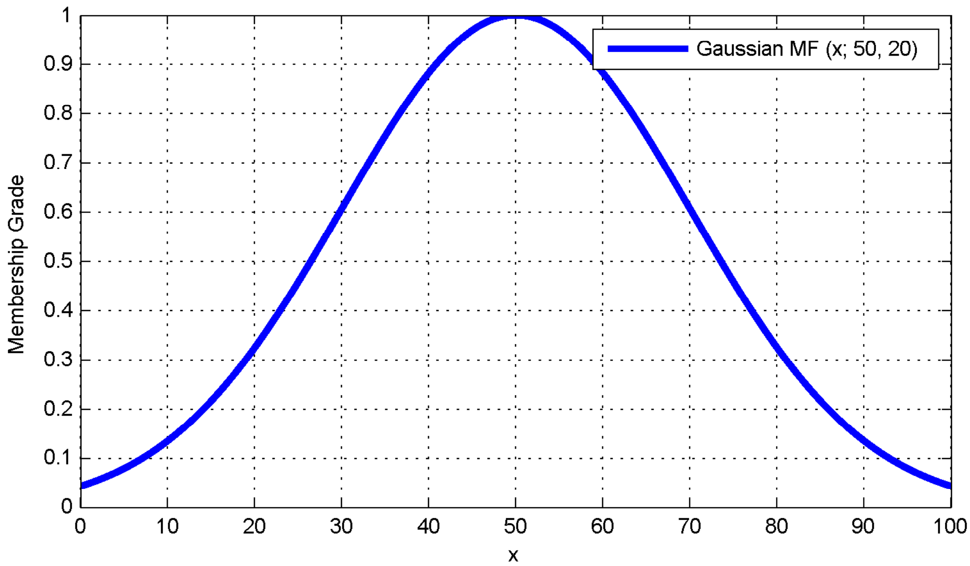

Figure 1.7. Example of Gaussian MF.

linguistic value such as "young" should be defined by a compatibility function which associates with each age interval in [0, 100] and a number in the interval [0, 1] which represents the compatibility of that age with the label young [47].

On the other hand, base variables are not sometimes well-defined for the linguistic variable like "appearance", because, for these kinds of linguistic variables, the mathematical MFs cannot be expressed. Although, for the example of the linguistic variable "appearance", it is not known how to express the degree of beauty, subjects should be still clustered, for example say 0.8 for X, 0.7 for Y, 0.9 for Z. But this kind of classification is just based on the impression which cannot be articulate or formalize in explicit terms. Furthermore, the important thing that should be called attention is that such definitions are meaningful to a human but not, at least directly, to a computer [47].

A fuzzy rule, also known as fuzzy implication or fuzzy conditional statement, is written as If-Then statements. Thus, it also called as fuzzy if-then rule which assumes the form where A and B are linguistic variables defined by a fuzzy set on universes

```
if x is A then
    y is B
end if
```

Figure 1.8. Fuzzy Logic If-Then Rule.

X and Y, respectively. Often "x is A" is called as "antecedent" or "premise" whereas "y is B" is called the "consequence" or "conclusion" [40, 47]. "If the pressure is high, then volume is low" or "if the road is slippery, then driving is dangerous" are the most widespread fuzzy if-then rules that people use in their daily lives.

1.3.4. Defuzzification Methods

Defuzzification is the process of producing a crisp value result in fuzzy logic method, given fuzzy sets and corresponding membership degrees. In other words, it is a reverse process of fuzzification. Basically, defuzzification is a mapping from a space of fuzzy control actions defined over an output universe of discourse into a space of non-fuzzy (crisp) control actions [49].

The process of converting the fuzzy output is called defuzzification. Before an output is defuzzified all the fuzzy outputs of the system are aggregated with a union operator. The union is the max of the set of given membership functions and can be expressed as:

$$\mu_{\mathrm{A}} = \cup \left(\mu_i(x) \right). \tag{1.30}$$

There are many defuzzification techniques but primarily only three of them are in common use:

(i) Center of Area/Gravity: It is the most commonly used defuzzification technique.

It is also called centroid defuzzification method. This method determines the center of the area of the combined membership functions. Calculated the centroid or center of gravity (COG) of the area under the membership function is found by Equation 1.31.

$$F_{\mathrm{COG}}^{-1} = \frac{\int \mu_{\mathrm{A}}(x)x\mathrm{d}x}{\int \mu_{\mathrm{A}}(x)\mathrm{d}x}. \tag{1.31}$$

(1.32)

(ii) Maxima methods: Maxima methods consider values with maximum membership. There are different maxima methods with different conflict resolution strategies for multiple maxima, e.g. first of maxima (FOM), last of maxima (LOM), and mean of maxima (MOM). If the aggregate membership function has a unique maximum, then MOM, SOM, and LOM all take on the same value [49].

(iii) Bisector method: The bisector is the vertical line that will divide the region into two sub-regions of equal area. It is sometimes, but not always coincident with the centroid line.

1.4. Criteria of Ergonomic Product Design

Ergonomics is a science focused on the study of human fit, and decreased fatigue and discomfort through product design. Ergonomics applied to any work station design requires to take into account how the products fit the people when they are using those. Especially human factors and ergonomic standards play an important role in facilitating the design of optimal working conditions with regard to human safety, health and general well-being, as well as system performance in the context of technological advances and opportunities for economic development worldwide [50]. Such standards offer guidance on the design of work systems, including tasks, equipment and workplaces as well as working conditions in relation to human capacities and limitations. When the products or workplace obey these standards at work, at school, or at home, the result can be more comfort conditions, higher productivity, and less stress. Knowing the study of anthropometry, posture of body segments, and workspace conditions provides healthy working environment for final users, and eventually provides higher productivity.

Standardization efforts help to recognize the significance of human factors and ergonomics discipline by focusing on the requirements that need to be taken into account during the design, development, testing and evaluation of workspace and systems. Human factor and ergonomic standards are developed through a process that aims to ensure that all the interests of potentially affected users are taken into account in the development process. Although the application of relevant standards by itself cannot always guarantee optimal design, it can provide clear and well defined requirements for ergonomic design process. By two important committee International Organization for Standardization (ISO) and European Committee for Standardization (CEN), many standardizations are accepted. General topics that are covered by them can be listed as follows:

- Safety of machines
- Vibration and shock considerations
- Noise and Acoustic considerations
- Lighting
- Respiratory protective devices
- Eye protection
- Head protection
- Hearing considerations
- Protection again falls
- Foot and leg protection
- Protective clothing
- Radiation protection
- Air quality
- Instruction processes [50]

When the above list is examined carefully, it is realized that human health is the most important considerations. By the help of the human factor and ergonomic standards and applications of national regulations, responsibilities of employees regarding occupational safety and health management are established. Thus, it can be said that the basics objective of ergonomics is to fit the task to the person by reducing the stresses, increasing efficiency, accuracy and safety, ensuring correct body posture and adapting working conditions to the person's physical requirements. The purpose of the ergonomics can be explained as follows:

(i) Fit the demands of work of the capability of a person in order to reduce stresses.
(ii) Design the task to enable it to be accomplished efficiently, accurately and safely.
(iii) Design workspace proportions to ensure correct body posture.
(iv) Adapt lighting, climate and noise etc. to suit a person's physical. requirement [51].

1.4.1. Human-Machine Interaction

The human-machine relationship is the center core of human factors. Human-machine systems like any system have an objective or purpose and consist of inputs and outputs. Every component in that system serves at least one function related to achievement of the system's objective. System components perform a combination of four basic functions:

(i) Sensing (information receiving)
(ii) Information processing (decision)
(iii) Information storage
(iv) Action [51].

Most injuries may be seen when human-machine interaction is not well which may have different raasons. For example operating a task in awkward posture or not defining ergonomic working principles well which contributes to a variety of musculoskeletal disorders are most populer reasons.

1.4.2. General Ergonomic Product Design Considerations

Due to the higher satisfaction level of the consumers thanks to the ergonomic improvements and successive results of studies of ergonomics, nowadays, the companies have showed more importance to the application of ergonomics design criteria. Produce successful products for customers is a vital endeavour for company. Especially, fulfillment of two goals of health and productivity are provided by ergonomic design criteria applications. Opposite to traditional design process which concentrates on functionality of product, modern design process includes comfort and personality considerations of product as well. Therefore, including human factors becomes necessary part of design stage by applying ergonomic design criteria. The creation of a new product or improvement of an existing product is a complex task which is characterized by uncertainty and variability. It requires the analysis of different aspects as target market, customer requirements, engineering specification, costs and performance attributes as well as ergonomic consideration.

In the previous parts, general concepts about workplace or product design considerations are mentioned. In this section, just considerations about product design are discussed. There are many important specifications that should be taken into account during the designing any products.

1.4.2.1. Anthropometric Data Specifications. Very first considerations during the ergonomic product design are statistical data describing human size, mass, and form of the products. Anthropometric data which is the science that deals with the measurement of size, mass, shape and inertial properties of the human body are also fundamental when developing biomechanical models to predicted human reach space and requirements. Measurements of physical properties of body segments help to better understanding the capabilities of those which are directly related with ergonomics. Thu human body skeleton is a frame on which the body is built, therefore protection of it is very essential [52].

- Structure of bone: For the purpose of occupational biomechanics, examining the whole bone as a composite is more meaningful than examining each of the structures separately. The most important mechanical properties of the whole bone are their strength and stiffness. When a bone is loaded to failure, it fractures, therefore designing any product according to the capability of the related bone structure is very essential. Moreover, bone has also a significant energy-storage capacity. The structure of body segments comprising a linkage system is used to identify the joint locations for the extremities [26].
- Volume and weight of body segments: Not only body tissues are mechanically stressed by external loads carried, pushed or pulled while performing a manual task, but also the effect of gravity on the mass of the body segments creates body-weight-related stresses.
- Body segment locations of center of mass: It is not sufficient to know the mass or weight of a body segment to perform a biomechanical analysis. One must also be able to locate where within the segment the gravitational effect of the distributed segment mass can be considered to act. Location of center of gravity is mostly used for biomechanical modeling for the human conditions chancing by external loads.

<u>1.4.2.2. Mechanical Work Capacity Evaluation.</u> One other significant parameter is to know the mechanical work capacity of the population who are the potential end user of the designing product. Joint mobility or range of motion and muscle strength data allow biomechanical models to be developed that can be used to predict both population's capacity to achieve various working postures and manual forces that can be produced in a given posture.

- Joint Mobility: Joint motion could be defined relative to a specific absolute posture. In order to avoid the musculoskeletal disorders, posture of the segments should be clearly defined. Age, gender, anthropometric dimensions and muscles are factors that affect the joint range of motion.
- Muscle strength evaluation: Strength is the maximum force that a group of mus-

cles can develop under prescribed conditions. Strength has directly effect on user's posture and joint angle during any activity. And lastly, static muscular strength values can provide important information about biomechanical capabilities of workers and thus assist in designing job to accommodate a large number of people. On the other hand, motion of body segment may require significant muscle force, simply to overcome inertia and accelerate the body segment masses. Therefore, measuring dynamic muscle strength before designing stage is important, too.

- Personal effects: Gender, age and anthropometry are also important factor of work capacity evaluations.

Anthropometric data analysis and mechanical work capacity evaluations must be done before any product design stage. It may not be directly related with design parameters but the results of them give good and sufficient knowledge about the potential customer As mentioned before, ergonomics is especially dealing with human-machine interaction in order to protect human health while doing any activities. Therefore the parameters of the product are assigned according to ergonomic design knowledge. On the other hand, some ergonomic considerations are directly related with designing parameters.

1.4.2.3. Performance Considerations. The number one reason for lost workdays in recent years is musculoskeletal overuse/overexertion injury which brings about decrease of both product performance and human performance. Products should be designed to prevent any injury which leads to decrease the performance. Also, consumptions of the energy while using the product also important. Consuming lower effort is always desired.

1.4.2.4. Easy of Use Considerations. If a product is manufactured according to ergonomic design criteria, it is automatically designed to be comfortable and easy to use, physically and psychologically. Ergonomic products are often advertised as reducing fatigue and repetitive strain, and boosting productivity, thus it is significant.

1.4.2.5. Aesthetics Considerations. Although, ergonomists and human factors researchers have made great contributions to the safety, productivity, ease-of-use, and comfort of human-machine-environment systems, aesthetics is largely ignored as a topic of systematic scientific research in human factors and ergonomics. However, companies generally assume that the most visually appealing product will probably be selected by the consumer, even though the product may be deficient in other aspects. Therefore, during the design stage, the visual aesthetics have became more important nowadays [53] .

1.4.2.6. Safety Considerations. Safety rules protect the consumers or users from any injuries while using the products. Products should be comfortable and should not lead to fatigue of the muscles, and cumulative disorders. Protecting eyes, upper and lower extremities and spine are the most crucial safety considerations.

1.4.2.7. Environmental Considerations. During the design stage, environmental conditions are also important. The ambience where the products will be used by consumers also affects the design parameters. Light, noise, heat and electrical considerations should be taken into account.

1.4.2.8. Vibration Considerations. Some products produce vibration while using them, however, it sometimes causes unwilling results when it is not under control. Composite of vibration induce signs and symptoms such as numbness, tingling of fingers, pain or reduced grip strength.

1.4.2.9. Human-Product Considerations. Another important consideration about designing adequate product is to learn the interaction between human and work place. According to perfect interaction between product and human, easy to use consideration is automatically gained.

Human hand is a very beautifully designed organ, capable of an infinite variety of configurations and functions. Unfortunately, certain types of daily and repeated manual exertions create cumulative trauma to the musculoskeletal systems of the upper extremity. Discomfort, pain and loss of function on the hand and wrist tissues have undesirable effects on daily life activities, therefore adequate product or tool design is necessary for protecting human health. Very first stage of getting an adequate product which is related with work posture is to understand the interaction between work factors, stress factors, tool factors, worker factors and physiological responses. Some critical considerations should be taken into account during the design stage in order to manufacture adequate products [26].

(i) Weight: First consideration is the weight of the product which is directly related with the stress and strain on the arm system. Also, resultant high force and moment being formed due to the heavy weight is one of the risk factor for the spine discomfort.

(ii) Shape and Size: Second criteria are about both product shape and the handle shape. The shape and size of a handle tool have a direct effect on both user's performance and biomechanical stress on the upper extremity. Keeping the hand and forearm to remain in alignment during the forceful grip exertions often necessitates specific handle configurations. If the shape tool requires an extreme wrist deviation, user generally tends to rise the arm in order to reduce the stress on the wrist. Although rising the arm decrease the stress and load on the wrist, it leads to biomechanical stress on the shoulder. Therefore, there is a physiological trade-off between the stress on the wrist and stress on the shoulder. A small amount of arm abduction at the shoulder up to 20^o from the vertical will not normally create excessive load moment, whereas a value greater than this rapidly increases the shoulder load moment [52]. Shape is also important for assisting the grip force, because if the handle is gripped firmly to avoid the slippage, both wrist abduction and extensor tendon compression occur. As a result a handle should have a shape which avoids high shoulder abduction and wrist deviation at the same time.

(iii) Handle Material Type Besides shape and size considerations, materials that are used for covering the handle should be taken into account for preventing slippage. Padded handles distribute the forces on the fingers and palmar tissues. Moreover, to avoid high palmar forces, the length of tool handle should be sufficient to distribute the forces on the lateral and medial sides of the palm and across the four nonthumb digits [52, 54].

(iv) Inner and Outer surface: Surface material is another important issue. Body of the product should be covered by the insulation materials against heat, vibration, and electricity. Also some other considerations should be taken into account according to operations. For example, a smooth surface is better if it is non-reflective, to avoid glare in brightly-lit work. Also, inner surface material is also very significant due to health issues.

(v) Clearance of handle and product: Another significant criterion for ergonomic handle design is to finger clearance considerations [52]. The gap between the kettle body and handle should not discomfort the user fingers. Probable pressure on the fingers due to the narrow gap is not desired by the users.

1.4.3. Kettle Design Criteria

The goal of ergonomic design is to maximize human safety, comfort, satisfaction and the efficiency of a particular operation. Strain, stress and fatigue on the upper extremities, lower extremities and spine should be minimized [52]. In order to design an ergonomic kettle which is suitable for a variety of users, specific ergonomic considerations should be taken into account.

1.4.3.1. Working Principles and Parts of a Kettle. A water kettle comprises a vessel having a bottom with upwardly adjoining circumferential side wall on which is formed a handle, having an electrical heating unit (resistance) arranged in proximity to the bottom and arranged to switched on and off by a mechanically control switch and having an actuating element (thermostat) for controlling the boiling period by vapor pressure and having a button acting on the lid and operable by hand so that its actuation releases the lid for opening [55]. A lid to close the vessel's opening can be opened and closed by a button generally mounted above the handle and on the lid. Generally in the lower are of the water there is an actuating element which is mechanically connected to a switch for switching on and off the heating unit which is generally arranged in proximity to the bottom [55].The kettle body is a top-open water container, having a handle protruded from the periphery at one side, and a spout for pouring water out of the kettle body. In order to observe the level of water which is put before heating, some part of body is made of a transparent material. This part is also called water level indicator [56]. It is sometimes observed that when water is heated, some impurities can precipitate within the water. Therefore, some kettles have filters that can remove impurities and precipitates from the water or can remove objectionable color, odor or bad taste from the water [57]. At the bottom of kettle is generally a sealed electric heating element which is called resistance. The flow of electricity on the resistor is converted to the heat. This resistance can be hidden or not be hidden. The disadvantages of the kettle without hidden resistance are about cleaning issues and restriction about the water putting in the kettle at the beginning of the heating operation. It is difficult to clean a resistance because of its shape and location in the kettle. Uncleared resistance which is covered by calcification is not preferred by most of the users. Also, non-hidden resistance should be covered by water at the beginning of the heating operation in order to prevent loss of heat. Conducting the heat from resistance to water can be done by conduction type of heat transfer therefore, if the resistance is not covered by water, heat is transferred to the air. Typically, there is an on/off switch and a thermostat which controls how hot the kettle gets.

As the current flows through the plug and the connection, the resistance becomes extremely hot and disperses the heat throughout the water, at this stage tiny bubbles are rising from the bottom. After water reaches boiling point, starts to agitate, and the stream comes out of the spout of the kettle. Thermostat as the temperature controlling device acts indirectly to the resistor. It is used for the controller to shut down the kettle when water becomes boiling temperature [54]. In Figure 1.9, you can see the standard circuit diagram Table 1.7, you can see the kettle bill of material (BOM).

In the Figure 1.10, you can see disassembly of an example kettle. In this figure all detailed parts can be seen easily.

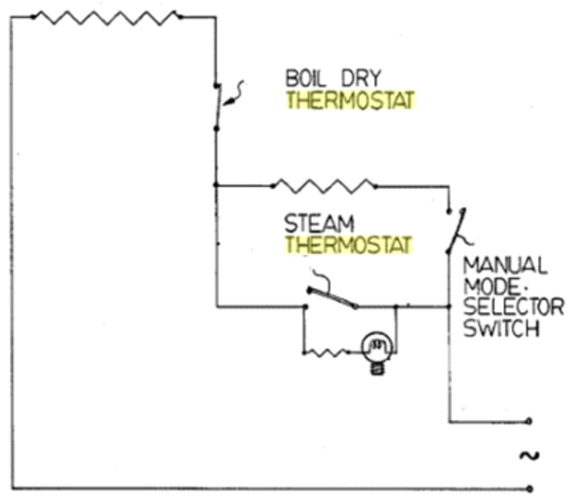

Figure 1.9. Standard circuit diagram of a kettle [49].

Table 1.7. Kettle Bill of Material (BOM).

Component	**Quantity**
Kettle body	1
Heating element (resistor)	1
Thermostat	1
Internal insulation	1
Cable Sheath	1
Cable Core	1
Plug	1
Handle	1
Lid	1
Switch	1
Filter	1
Small components	1

Figure 1.10. Parts of the kettle; 1. Power cable with Strix P69 Cordless System, 2. Base moulding, 3. Water reservoir, 4. Handle with lid mechanism, 5. Heating Element, 6. Removable filter, 7. Bottom of base moulding, 8. Lid release mechanism, 9. Lid release button, 10. Lid release mechanism, 11. Rubber seal, 12. Strix R72 kettle control, switch and thermal fuse, 13. LED, 14. Bi-metallic disk [57].

1.4.3.2. Ergonomic Kettle Design Criteria. There are many important considerations which should be taken into account during the ergonomic kettle design.

- One of the most significant ergonomic considerations is about the kettle handle. The handle is used to transmit force from the users muscle and body to the object. It is directly related with hand and upper extremity posture of the user. Unergonomic handle design leads to standing the hand as awkward posture of hand which brings about stress and fatigue on the muscles and wrist [58]. In order to design an effective kettle handle, there are some basic rules that should be considered. Firstly, the most effective transmission of lifting force occurs when the handle and hand interact in compression rather than shear. Secondly, all handles should be smooth with cylindrical (25 mm minimum) cross section. This removes any pressure on the palm when handle is covered by the hand [58].
- Secondly, the minimum area between the handle and body surface is important in order to prevent instant pressure on the fingers while pouring the water [58].
- One other important parameter is weight and shape of the kettle reservoir. Shape is most significant parameter that determines the location of center of gravity. The weight, on the other hand, is directly related with stress on the wrist and hand. The weight of the kettle when full should not exceed 3 kg as this is just below single arm lift of typical woman for not forcing the shoulder [58].
- The ergonomic data associated with hand allows for an accurate design. Therefore, it is important to know the anthropometric measurements of population where the kettle is planned to sell. Especially handle must be longer than the 95^{th}% the hand breadth of related population, because shorter handles may lead to undesired pressure on the palm. Furthermore, maximum handle diameter should be determined by 5^{th}% the maximum grip diameter of related population [58].

2. PROPOSED MODELS FOR INTEGRATING KANO MODEL, QFD AND FUZZY LOGIC

2.1. Rationale for the Proposed of the New Approaches

There are number of studies in the literature about applications of quality tools with ergonomic design criteria, however a review of literature indicates that there are only a few studies on determining ergonomic product design by QFD [22]. The most exciting part of QFD studies is that they are customer-oriented applications, which mean that the priorities are always customer expectations and needs. After examining the QFD applications, it is realized that QFD has several weak points, besides its many advantages. These deficiencies are as follows [1, 3, 16]:

- QFD assumes that customers have previous knowledge about the product or service that it is used for. Although, this assumption provides customers to judge their needs more consciously, it leads to skip customer comments about new and/or innovative changes in the product or services.
- Secondly, QFD assumes that there is a linear relationship between two of them which means that if the product performance is improved, then customer satisfaction increases. However, this kind of relationship should not be generalized, because every product feature provides different amount of satisfaction.

In order to get rid of those weaknesses, Kano Model was suggested to be used with QFD [1, 3, 16]. A new perspective that Kano Model brings to QFD is to classify the "what lists" according to customer satisfaction level. It should not be forgotten that a competitive product or service should meet must-be attributes in order to respond customers' basic expectations, also should maximize the one-dimensional attributes for increasing customer satisfaction and should include as many attractive attributes as possible to provide differentiation when comparing with competitors. Therefore, in order to reach the final users truly, the functions of the product or service must be well-defined at the design stage.

After reviewing the related literature about combined approaches of Kano Model and QFD, it was found that the way of their integration is not based on very powerful assumptions. In most of the articles, modified formula is used for updating the improvement ratio (IR) [3, 10, 14]. For example in [3] Kano and QFD were integrated in order to help accurately and deeply understand the nature of VOC. They used Equation 1.6 as a starting point and converted the formula to the following equation:

$$s = cp^{(k)} \tag{2.1}$$

where s and p indicate satisfaction level and performance level, respectively. And c is a constant. If the current customer satisfaction degree and the performance level of the product or service are assigned as s_0 and p_0, and customer satisfaction target and desired performance target are assigned as s_1 and p_1 respectively. Then the Equation 2.2 can be presented as $s_0 = cp_0^{(k)}$ and $s_1 = cp_1^{(k)}$.These equations are used for updating the Importance Ratio (IR_0) as follows:

$$\frac{s_1}{s_0} = \frac{cp_1^{(k)}}{cp_0^{(k)}} \tag{2.2}$$

$$\frac{s_1}{s_0} = \left(\frac{p_1}{p_0}\right)^{(k)} \tag{2.3}$$

$$IR_0 = \frac{s_1}{s_0} = \left(\frac{p_1}{p_0}\right)^{(k)} \tag{2.4}$$

Consequently, it can be got:

$$IR_{\text{adj}} = IR_0^{\left(\frac{1}{k}\right)} \tag{2.5}$$

Where IR_{adj} is the adjusted improvement ratio, and IR_0 is the original improvement ratio and k is the Kano model parameter for different categories. A possible set of k values, that were proposed in [3], are “1/2”, “1” , “2” for basic, one-dimensional and attractive attributes, respectively. However, we identify three problems with this proposed formula.

- First one is the assigned values for the Kano model parameters. They are proper according to Equation 2.10, however it seems that assigned k values "1/2", "1" and "2" are arbitrarily chosen.
- Moreover, if only three Kano clusters (must-be attributes, one-dimensional attributes, and attractive attributes) are considered, it seems there is no problem. However, if indifference attributes is included to the model, then a problem appears. As mentioned in introduction part, the Kano model parameter for indifference attributes is 0. Thus Equation 2.5 becomes undefined for the indifference attributes.
- This formula does not have the effects of absolute importance of customer requirement, which will be explained in next section. Shortly, importance of customer requirements shows that which of satisfaction level or dissatisfaction level have more effects on customers' choices.

Another suggestion was done in [31] who offered a new transformation function that includes both Kano model parameter and absolute importance of customer expectations. The proposed formula is at below.

$$IR_{\mathrm{adj}} = (1+m)^k \, IR_0 \tag{2.6}$$

Where IR_{adj} is the adjusted improvement ratio, IR_0 is the original improvement ratio, k is the Kano model parameter for different categories and m is equal to maximum of absolute values of dissatisfaction index (DI) or satisfaction index (SI). SI indicates how much the influence on customer satisfaction is increased by providing a particular customer attribute, whereas DI shows how much the influence on customer satisfaction is decreased by not providing that customer requirement. The calculation procedures will be explained in Section 2.1.4. The problem in this suggestion is that it gives unnecessary importance to attractive attributes and very low significance to the basic attributes [32].

To overcome the indicated deficiencies in the existing approaches, Fuzzy Logic Theory (FLT) was decided to be used for combining the Kano Model and QFD because of its many-valued logic and its reasoning based on approximations rather than exact truths. In [18], QFD implementation was used based on Fuzzy Kano Model applied to product lifecycle Management (PLM). Although [18] provides a new perspective for understanding the FL and Kano Model integration, there are still some weak assumptions about integrating the Fuzzy Kano Model into the QFD. Study suggests a new integration of Kano Model and FLT, however it does not cover the indifference customer cluster in the procedure. When we compare the present study and [18], basically three differences were observed.

(i) In present study, fuzzy will not only be integrated with Kano Model but also be combined with QFD. Details of the integration will be explained in the following parts. But in [18], FL was just used with Kano Model.

(ii) The most important difference is that their study did not cover the indifference attributes because Fuzzy Kano Model was embedded into the QFD by using Equation 2.5 which becomes undefined when k equals to zero.

(iii) Another important difference is evaluated by assigning the customer requirements to the Kano clusters. In our study k values will be calculated by weights of Kano Questionnaire and therefore every customer requirement has different k value which is thought as more logical. However, [18] used FL before assigning the cluster, therefore at the end some results may be ignored in calculations.

As a result, in this thesis two kinds of quality models are proposed. First one combines Kano Model and QFD whereas second model combines Kano Model, QFD and FLT together. In order to illustrate the improvements of the new approaches, a modified QFD-Kano Model and Fuzzy Kano-Fuzzy QFD models are compared with existing models n the literatures. The only difference of two alternative models is that, in the first model that consists of Kano Model and QFD, the crisp values were used whereas in the second model, that also includes FLT, the partial set memberships were used. Hence, the models are compared not only with existing models but also with each others in order to reveal the gains of Fuzzy Logic Theory.

2.2. Proposed Model 1: Modified Kano-QFD Model (MKQFD)

2.2.1. Rationale of the MKQFD

As mentioned in the section 2.1, this model is developed for two reasons .First one is to improve the deficiencies that we indentified in the existing models in the literature. Kano model is embedded into the QFD with different steps. The comparison will be done in section 2.2.3 after explaining the proposed model in detail. Second reason is to understand the effects of the Fuzzy Logic in proposed model 2. The differences between two models are the values that are used for calculations of relative weights of customer expectations and relative weights of engineering specifications. In the first model, crisp values are used whereas in the second model, fuzzy values are used. It is attempted to the answer of one significant question: "Are there any effects of Fuzzy Logic Theory on the results of the proposed model of integration Kano model, QFD and FLT".

2.2.2. MKQFD Algorithm

2.2.2.1. Step 1: Determining Customer Demands. For better design, the first thing that designers should know is the customers' real expectations from the product or services which may provide them to focus on right criteria. But the same time, it should be known which customer expectations are more crucial than to others. As mentioned before, if the expectation of customers from the product or service is to provide a differentiation, then it has some attractive attributes besides basic requirements. On the other hand, if the demand from it is to compute with equivalent product or service of other competitors, then it should include maximum one-dimensional requirements besides basic attributes. Therefore, it should also be decided what the product or service is used for.

In order to learn the customer expectations and the real purpose of the product or service which may not come out clearly by QFD, Kano model is suggested. It also provides to get rid of the weaknesses of QFD; that are the assumptions about customers' previous knowledge and linear relationship between customer satisfaction and product or service performance.

The first step of Kano Model applications is to know customers' wants and needs from the product or service which can be found by market survey. Telephone surveys, mail-box surveys, questionnaires, one-by-one conversations can be help to learn the awareness of customers' expectations about product or service. At this point, customers should be totally free. The researchers should not direct them by bias questions or any detail explanations about the product or service. According to very basic, clear and understandable questions, the pure customer thoughts should be gathered. Because the customers are set free, some irrelevant answers may be gathered. Therefore, it is important to analyze all expectations carefully and to eliminate unnecessary information for the study.

2.2.2.2. Step 2: Making Kano Questionnaire. Based on the results of step 1 (determination of main customer needs which will also be listed as "what lists" in the QFD), the Kano questionnaire is prepared. For each customer expectations, positive and negative types of questions, named as functional and dysfunctional questions, respectively, must be asked in the questionnaire.

For the proposed models some changes were done and they will be explained while proposed models are being defined. The first modification in application of Kano Model comparing with the examples in the literature was done at this point. First offer in the proposed model is that when arranging the questions, functional and dysfunctional questions for each requirement should not be listed successively but in random order, because when they are in successive orders, the responders are mostly affected by their first answers. They automatically try to give opposite answers, even there is no need. For example, one can be answer both functional and dysfunctional questions of any requirement as "I am neutral". Furthermore, some responders cannot really think about the meanings of answers when the choices are in the same order as:

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live with it that way.
(v) I dislike it that way.

In order to provide people to draw attention on Kano questionnaire while answering the questions, it is recommended to randomize both order of questions and order of answers. Randomization forces people to be more careful while reading and answering the questions. Also randomization is the first rule of the statistical studies. It prevents to get biased error during the study and to make wrong judgments about the subjects and criteria of the study. Therefore, we make positive contributions to the existing models about the statistical considerations by asking the functional and dysfunctional questions in random order and by listing the choices in random order.

In many questionnaires in the literature, choices are organized according to Likert-type scale, an ordered one-dimensional scale form which respondents choose one option that best aligns with their view. In the Likert-type scaling, there is a small increment about the agreement to the question between the successive choices. Mostly the answers are ordered as follows.

(i) Strongly disagree
(ii) Somewhat disagree
(iii) Undecided
(iv) Somewhat agree
(v) Strongly agree

The main differences between the Kano Questionnaire choices and Likert scaling are the meaning of the choices and their orders. If the answers are checked carefully one more time, it is seen that there is no analogy between the successive answers. For example, the connection between the "strong disagreement" and "somewhat agreement" is nothing with the connection between "I like it that way" and "it must be that way".

In this thesis, the purpose is not to catch the agreement about the product or service feature. Therefore, Likert scaling format were not used in this study.

2.2.2.3. Step 3: Evaluation of Kano Questionnaire. The next step of the KQFD is to evaluate all answers of each customer attribute in the Kano evaluation table. Reading the Kano evaluation table is very simple. One should just look at the intersection cell of functional and dysfunctional answers on the evaluation table. Then, the answers are counted and according to frequency of them, the dominant customer of view determines the cluster of the requirements (any of attractive attributes, one-dimensional attributes, basic attributes, indifference attributes, reversible attributes or questionable attributes) which will be listed in the first column of the HOQ. For example, if the result of Kano model questionnaire indicates that customer attribute 1 has 5 A, 30 O, 60 M, 1 R, and zero Q. Then it belongs to must-be requirements due to its highest frequency. The coefficients of the Kano clusters are found according to the relationship formula that was explained in introduction part of Kano model theory. As mentioned before, the relationship between customer satisfaction level and the product or service performance can be generalized as follows:

$$s = f(k, p) \tag{2.7}$$

where s indicates satisfaction level, p shows performance of the product and k indicates Kano model category. For one-dimensional requirements, linear relationship between change in customer satisfaction and change in product performance can be express as

$$\frac{\Delta s}{s} = \frac{\Delta p}{p} \tag{2.8}$$

where Δs and Δp indicate a small shift of s and p, respectively. For must-be requirements, the expressions becomes as follows

$$\frac{\Delta s}{s} < \frac{\Delta p}{p}. \tag{2.9}$$

On the other hand, attractive quality elements provide high satisfaction level increments. Therefore, the equality changes as follows

$$\frac{\Delta s}{s} > \frac{\Delta p}{p}. \tag{2.10}$$

According to these three equations, by using the parameter k, above three relationship formulae can be expressed by one equation

$$\frac{\Delta s}{s} = k\frac{\Delta p}{p}. \tag{2.11}$$

For attractive attributes k is larger than 1, for one-dimensional attributes k equals to 1 and for must-be attributes k is between 0 and 1. In many articles in literature, these coefficients are chosen as 0, 0.5, 1 and 1.5 or 2 for indifference attributes, basic attributes, one-dimensional attributes and attractive attributes, respectively [3,23,32]. Hence, the recommended values of k used in this thesis are 0, 0.5, 1 and 1.5 which is listed in the second column in the HOQ which can be shown in Table 2.1.

Table 2.1. The Kano-QFD template.

				HOW LISTS /ENGINEERING SPECIFICATIONS																	
	KANO CLASSIFICATION	KANO MODEL INDEX	ADJUSTMENT FACTOR (m)									IMPORTANCE	VALUE of IMPORTANCE	OUR PRODUCT TODAY	COMPETITOR 1	COMPETITOR 2	OUR PRODUCT FUTURE	IMPROVEMENT RATIO	SALES VALUE	ABSOLUTE VALUE	RELATIVE WEIGHT
WHAT LISTS/ CUSTOMER EXPECTATIONS				HOWs vs WHATs																	
ABSOLUTE WEIGHT																					
RELATIVE WEIGHT																					

2.2.2.4. Step 4: Determining the AdjustmenFactorst. The next step is to find the Kano Model adjustment factor, mostly indicated as "m" in the literature. With the help of Kano model indices, it can be understood the customers' view point on each requirements and thus, they can be classified based on their importance level. However, Kano Model also provides designer teams to catch the reaction when any of requirements appears or disappears in the product or service. The absolute importance of customer requirements are calculated by two terms; impact on customer satisfaction index (SI) and impact on customer dissatisfaction index (DI). SI indicates how much the influence on customer satisfaction is increased by providing a particular customer attribute, whereas DI shows how much the influence on customer satisfaction is decreased by not providing that customer requirement [1]. SI and DI which are used in many study in the literature are calculated by using following equations:

$$SI = \frac{f_{\mathrm{A}} + f_{\mathrm{O}}}{f_{\mathrm{A}} + f_{\mathrm{O}} + f_{\mathrm{M}} + f_{\mathrm{I}}} \tag{2.12}$$

$$DI = -\frac{f_{\mathrm{M}} + f_{\mathrm{O}}}{f_{\mathrm{A}} + f_{\mathrm{O}} + f_{\mathrm{M}} + f_{\mathrm{I}}} \tag{2.13}$$

where f_{A}, f_{O}, f_{M}, and f_{I} are ffrequency of attractive requirement, frequency of one-dimensional requirement, frequency of must-be requirements and frequency of indifference requirements respectively. According to satisfaction and dissatisfaction degrees, it is attempted to understand which condition (product including or not including that attribute) has more influence on customers' purchase on product or service. With the help of dissatisfaction and satisfaction levels, adjustment factors for all needs are calculated as follows:

$$m = max\{SI, |DI|\} \tag{2.14}$$

where, m indicates the adjustment factor for the customer attributes.

From now on, the only job that the designer team should do is to interpret the knowledge which is gathered from the customers. Determining the importance of all customer requirements based on the designer team's point of view, making competitor analysis, setting future target are next steps, respectively, for evaluating the absolute and relative weights of each customer attribute which will be used for calculating the effects of engineering specifications later on.

2.2.2.5. Step 5: Determining the Importance of Customer Requirements. Significance of each requirement for customers and designers shows some differences most of time, thus it is also necessity to list the designers' importance rank besides customers' order for all attributes. The importance which is listed in the first column of right matrix on HOQ is one of the multiplier of absolute weight of the attributes. Like most of articles, 5 degree scaling, "very low", "low", "medium", "high" and "very high" is used in the proposed model. Numerical representation of each level which is written on nearby column of importance is 1, 2, 3, 4 and 5 respectively.

2.2.2.6. Step 6: Analysis of Competitors and Setting Future Target. Competitor analysis which helps to determine future target of company about its product or service is the next step of the first proposed model. As mentioned before, must-be requirements are necessary in order to meet the basic expectations of customers, but in order to become a favorite brand, one-dimensional requirements that bring customer satisfaction should be covered by the product or services whereas differentiation among the other companies is just provided by the attractive attributes. Therefore, analyzing other companies is very important for not aiming unnecessary and inaccessible future target. In this step, scoring the conditions of the current companies and at least two more competitors about each requirements (min=1, max=5) is recommended [1, 6, 7, 41, 44]. According to these results, future target value which will be used for calculating the improvement ratio (IR) is determined.

$$\text{improvement ratio (IR)} = \frac{\text{(future goal)}}{\text{(current customer satisfaction level)}} \tag{2.15}$$

2.2.2.7. Step 7: Sales Point Calculation. The proposed model brings a new approach to the traditional QFD model in determining the scoring the sales point value of each requirement. In the literature, sales point values explains as criteria that shows the companies' competitive advantage, therefore highest score is given to the requirement about the field that the company is better when comparing with other companies' conditions. On the other hand, if any requirement that the company does not have much capability for is scored as lowest value. Competitive advantage provides more sales when comparing with rivals' sale, therefore companies effects should be included in to the calculation of weights of customer expectations by sales points. The most common values assigning for sales points are 1 for no sales point, 1.2 for medium sales point and 1.5 for strong sales point [2, 19, 20]. However, in this study, sales points are fed from the Kano classification. Calculations are done according to results of Kano Questionnaire. The products which include any attractive attributes are mostly preferred by customers, therefore these kinds of requirements have a positive effect on sales quantity. Oppositely, indifference attributes have not much effect on customers for choosing the product, therefore this type of attribute should have a lower sales point contribution for the company. Thus, a new kind of sales point calculation is proposed for the study. In order to consider all answers of Kano questionnaire of each customer expectation, weight of all choices are calculated Firstly, the weights of the all clusters are calculated by dividing the frequency of each attribute with summation of the attractive, one-dimensional, must-be and indifference attribute frequencies. Following equation shows the way of calculation

$$w_j = \frac{f_j}{f_{\mathrm{A}} + f_{\mathrm{O}} + f_{\mathrm{M}} + f_{\mathrm{I}}} \qquad (2.16)$$
$$j = A, O, \ldots, I$$

where w_{j} represents the weight of Kano cluster j and f_{j} represent frequency of Kano cluster j. Also, f_{A}, f_{O}, f_{M}, and f_{I}, indicate the frequency of attractive attribute, one-dimensional attribute, must-be attribute and indifference attribute, respectively.

Then, weights of every Kano cluster are multiplied with the corresponding Kano Model index in order to calculate the sales point of customer expectations. Kano index are assigned as 0, 0.5, 1 and 1.5 for indifference attribute, must-be attribute, one-dimensional attribute and attractive attribute, respectively. Next formula shows the proposed calculation of sales points of n customer expectations.

$$SP_{\mathrm{i}} = w_{\mathrm{A}} \times k_{\mathrm{A}} + w_{\mathrm{O}} \times k_{\mathrm{O}} + w_{\mathrm{M}} \times k_{\mathrm{M}} + w_{\mathrm{I}} \times k_{\mathrm{I}} \qquad (2.17)$$
$$i = 1, 2, \ldots, n$$

where SP_{i} indicates sales point of customer expectation i. w_{A},w_{O},w_{M} and w_{I} shows weight of attractive attribute, one dimensional attribute, must-be attribute and indifference attribute, respectively. Similarly, k_{A}, k_{O}, k_{M} and k_{I} represents Kano model indices of attractive attribute, one dimensional attribute, must-be attribute and indifference attribute, respectively [23, 24].

New way of scoring the sales points provides many advantages when comparing with existing models in the literature. First of all, in the traditional QFD model, sales points which show competitive advantage of the company are scored by the marketing department of the companies. However, in our model it is fed by Kano Model Questionnaire, which means competitive advantage is also determined by customers themselves. In the traditional Kano-QFD models, which mostly use Equation 2.5, indifference attributes are not covered. Because when this formula is used for indifference attributes where kano index, k, is zero, it becomes undetermined, however, in our case all clusters are covered. Other advantage of the proposed model is that the contributions of all clusters are covered by proportional to their weights. In the existing model only the highest value of the Kano clusters are used.

2.2.2.8. Step 8: Calculation of Absolute and Relative Weights. At this point, designer team has all necessary information in order to calculate the absolute and relative weights of all customer attributes which are one of the multiplier of final calculations about the engineering specifications. Relative weights are nothing, but just the conversion of absolute values to the percentages. They were calculated by dividing all absolute weights with maximum absolute weight of customer expectations. Therefore, “1” is calculated for the most important customer attributes. And ratings of the others are decreasing successively till “0”. The relative and absolute weights formulae are as follows as indicated in the literature [1, 3]:

$$\text{Absolute Weight} = (m_\text{i} \times \text{importance} \times IR_\text{i} \times \text{sales point}_\text{i}) \tag{2.18}$$

where m_i indicates the adjustment factor of customer requirement i, and IR_i shows improvement ratio of customer attribute i as indicates in the literature [1, 3].

$$\text{Relative weight} = \frac{(\text{absolute weight}_\text{i})}{(\text{maximum absolute weight})} \tag{2.19}$$

<u>2.2.2.9. Step 9:Determining Engineering Specifications.</u> This step is the part where the real design specification is involved into the model. Product requirements or how lists are design characteristics that describe the customer requirements as expressed in the language of the designer and engineers, therefore it is very significant to list all specifications. One other important thing about how list is that they are mostly expressed by measurable units.

<u>2.2.2.10. Step 10: Determining the Relationships between What Lists and How Lists.</u> After making all calculations about the customer requirements, finding the relationship between what list and how list should be determined. To build the relationship matrix between the customer attributes and engineering specifications, it is necessary to establish whether or not a relationship exists between every "what" and every "how". All relationships are categorized either strong, medium or weak relationship. A score 9 is used to indicate strong relationship between what lists and how list. A score of 3 signifies a moderate relationship and 1 indicates weak relationships. These score are all accepted by many researchers, therefore this rating is recommended to use in this study, too [1, 22, 24, 36]

<u>2.2.2.11. Step 11: Calculations of Weights of Engineering Specifications.</u> The last step is to calculate the relative and absolute weights of all technical specifications. This calculation is one of the classical step of QFD approach, and no updating is done to this

step. It has two multipliers: relative weights of all customer requirements and the relationship between what lists and how lists. If n customer requirements and m technical specification exist, then absolute and relative weights of all m engineering specification are found as indicated in the literatute [1, 3]:

$$\text{absolute weight}_\text{z} = \sum_{i=1}^{n} \text{relative weight of customer atribute}_\text{i} \times \text{relationship}_\text{iz} \quad (2.20)$$

$$i = 1, 2, \ldots, n$$

$$z = 1, 2, \ldots, m$$

$$\text{relative weight}_\text{z} = \frac{\text{absolute weight}_\text{z}}{max(\text{absolute weight})} \quad (2.21)$$

The output of HOQ gives the importance rank of all technical requirements which is a good guide for designer teams in order to show which engineering specification is more significant than the others. As a result by using Kano model and QFD, customer languages with the help of their satisfaction levels are translated to the engineering language.

2.2.3. Comparison of the Proposed Model and Existing Kano-QFD Models

In the literature, there are many Kano-QFD integration models. Generally in the models, Kano Models are used for updating the improvement ratio (IR) values. In our case, Kano Model is used for both calculating adjustment factor and sale points scoring. Comparison can be seen better in Table 2.2.

Table 2.2. Comparison of existing Kano-QFD Model and MKQFD.

Steps	**Existing Kano-QFD Models in the Literature**	**Proposed Model I: Modified-Kano QFD (MKQFD)**
Step 1	Determining customer expectations with market survey.	Determining customer expectations with market survey.
Step 2	Making Kano Questionnaire according to results of market survey.	Making Kano Questionnaire according to results of market survey. Here, Kano Questionnaire and choices of the questions are listed in randomized manner which prevents biased error.
Step 3	Evaluations of Kano Questionnaire according to Kano Evaluation: Kano model indexes are assigned by crisp values. Indifference Attributes: 0 Must-Be Attributes: 0.5 One dimensional Attributes: 1 Attractive Attributes: 1.5	Evaluations of Kano Questionnaire according to Kano Evaluation: Kano model indexes are assigned by crisp values. Indifference Attributes: 0 Must-Be Attributes: 0.5 One dimensional Attributes: 1 Attractive Attributes: 1.5
Step 4	Determining the adjustment factors (m) for each customer requirements.	Determining the adjustment factors (m) for each customer requirements.

Table 2.2. Comparison of existing Kano-QFD Model and MKQFD (cont.).

Steps	Existing Kano-QFD Models in the Literature	Proposed Model I: Modified-Kano QFD (MKQFD)
	$SI = \frac{f_{\mathrm{A}}+f_{\mathrm{O}}}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, DI = -\frac{f_{\mathrm{M}}+f_{\mathrm{O}}}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}; m = max\{SI, \|DI\|\}$	$SI = \frac{f_{\mathrm{A}}+f_{\mathrm{O}}}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, DI = -\frac{f_{\mathrm{M}}+f_{\mathrm{O}}}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, m = max\{SI, \|DI\|\}$
Step 5	Assigning the importance of customer expectations and analyzing the competitors' conditions.	Assigning the importance of customer expectations and analyzing the competitors' conditions.
Step 6	Analysis of competitors, setting future target and finding IR. $\text{improvement ratio (IR)} = \frac{\text{(future goal)}}{\text{(current customer satisfaction level)}}$ In the existing models, adjustment ratio is updated by generally two different models. Both models are accepted by the authors. They are as follows:	Analysis of competitors, setting future target and finding IR. $\text{improvement ratio (IR)} = \frac{\text{(future goal)}}{\text{(current customer satisfaction level)}}$

Table 2.2. Comparison of existing Kano-QFD Model and MKQFD (cont.).

Steps	**Existing Kano-QFD Models in the Literature**	**Proposed Model I: Modified-Kano QFD (MKQFD)**
	(i) $IR_{\text{adj}} = (IR_0)^{(1/k)}$ (ii) $IR_{\text{adj}} = (1+m)^k IR_0$	
Step 7	Assigning the Sales Points (SP) of customer requirements. Generally, these values are determined by the marketing department of the company.	Sales point (SP) calculations of customer requirements. They are done by firstly calculating the weights of Kano Clusters and then finding the sales points. $w_j = \frac{f_j}{f_{\text{A}}+f_{\text{O}}+f_{\text{M}}+f_{\text{I}}}, j = A, O, \ldots, I$ $SP_{\text{i}} = w_{\text{A}} \times k_{\text{A}} + w_{\text{O}} \times k_{\text{O}} + w_{\text{M}} \times k_{\text{M}} + w_{\text{I}} \times k_{\text{I}}, i = 1, 2, \ldots, n$
Step 8	Calculation of absolute and relative weights of customer requirements.	Calculation of absolute and relative weights of customer requirements.

Table 2.2. Comparison of existing Kano-QFD Model and MKQFD (cont.).

<table>
<tr><th>Steps</th><th>Existing Kano-QFD Models in the Literature</th><th>Proposed Model I: Modified-Kano QFD (MKQFD)</th></tr>
<tr><td></td><td>$$\text{Absolute Weight} = (m_{\text{i}} \times \text{importance} \times IR_{\text{i}} \times \text{sales point}_{\text{i}})$$
$$\text{Relative weight} = \frac{(\text{absolute weight}_{\text{i}})}{(\text{maximum absolute weight})}$$</td><td>$$\text{Absolute Weight} = (m_{\text{i}} \times \text{importance} \times IR_{\text{i}} \times \text{sales point}_{\text{i}})$$
$$\text{Relative weight} = \frac{(\text{absolute weight}_{\text{i}})}{(\text{maximum absolute weight})}$$</td></tr>
<tr><td>Step 9</td><td>Determining engineering specifications.</td><td>Determining engineering specifications.</td></tr>
<tr><td>Step 10</td><td>Determining the relationship between What Lists and How Lists. Here relationships are assigned by crisp values.<table><tr><td>Weak Relationship</td><td>1</td></tr><tr><td>Moderate Relationship</td><td>3</td></tr><tr><td>Strong Relationship</td><td>9</td></tr></table></td><td>Determining the relationship between What Lists and How Lists. Here relationships are assigned by crisp values.<table><tr><td>Weak Relationship</td><td>1</td></tr><tr><td>Moderate Relationship</td><td>3</td></tr><tr><td>Strong Relationship</td><td>9</td></tr></table></td></tr>
<tr><td>Step 11</td><td>Calculations of absolute and relative weights of engineering specifications.</td><td>Calculations of absolute and relative weights of engineering specifications.</td></tr>
</table>

Table 2.2. Comparison of existing Kano-QFD Model and MKQFD (cont.).

Steps	**Existing Kano-QFD Models in the Literature**	**Proposed Model I: Modified-Kano QFD (MKQFD)**
	$\text{absolute weight}_{\text{z}} =$ $\sum_{i=1}^{n} \text{relative weight of customer atribute}_{\text{i}} \times \text{relationship}_{\text{iz}}$ where $i = 1, 2, \ldots, n$ and $z = 1, 2, \ldots, m$. $\text{relative weight}_{\text{z}} = \frac{\text{absolute weight}_{\text{z}}}{max(\text{absolute weight})}$	$\text{absolute weight}_{\text{z}} =$ $\sum_{i=1}^{n} \text{relative weight of customer atribute}_{\text{i}} \times \text{relationship}_{\text{iz}}$ where $i = 1, 2, \ldots, n$ and $z = 1, 2, \ldots, m$. $\text{relative weight}_{\text{z}} = \frac{\text{absolute weight}_{\text{z}}}{max(\text{absolute weight})}$

2.3. Proposed Model 2: Fuzzy Kano & Fuzzy QFD Model (FKFQFD)

2.3.1. Rationale of the FKFQFD

Second model is the second proposed model of this study. The only difference between two models occurs by using fuzzy theory in the second model. First model is just established and evaluated for the comparison of this model. Comparison shows if there is an improvement being provided by the Fuzzy model. Actually same steps are applied for this second model, however, this times calculations are not done by crisp values. Instead of crisp set membership, fuzzy sets membership is used. For better following, the same steps are repeated while explaining the proposed model.

This proposed model provides new advantages when comparing with existing models. Firstly, Kano model and Fuzzy Models are embedded into the QFD with different steps. The comparison will be done in Section 2.3.3 after explaining the proposed model in detail. Improvements are firstly provided by randomizing the order of functional and dysfunctional questions in the Kano Questionnaire. It prevents to get biased error. Secondly Kano Questionnaire results are used for scoring the Sales Points. In the existing models, k indices can be assigned by the highest frequency of the Kano clusters whereas in the proposed model k indices are calculated by the weights of all Kano clusters therefore all clusters have contribution for calculating the k values. Lastly, in the proposed models sales points are also represented by fuzzy numbers.

2.3.2. FKFQFD Algorithm

2.3.2.1. Step 1: Determine Customer Demands. As mentioned before, the initial and the most critical step of combining the QFD and Kano Model process is the identification of what customer wants and expects from the product or service. Several methods including customer panels, focus group discussions, one-by-one interviews with final users, customer complaints and customer database etc, can be used to establish what lists. In order to get the pure thoughts of customers about the product or service, biased questions and explanations should not be used.

2.3.2.2. Step 2: Making Kano Questionnaire. According to market survey performed in step 1, both relevant and irrelevant customer needs that will be used in the Kano questionnaire can be gathered. Therefore, analyzing the expectations should be done very well in order to catch relevant information with study. Relevant and enough number of expectations should be listed as what lists in the model, hence study is not departed from its own purpose. After determining final customer expectations or what lists, pair of questions should be asked for all of them. The question pair includes one functional and one dysfunctional form of same question and this provides deeper understanding of customer's opinion about the product attribute. The functional form describes the customer's reaction if the product has certain characteristic. One the other hand, the dysfunctional form captures the customer' reaction if the product does not have that attribute [1]. Both form of question includes five response options which will be listed in the step 2 of first model algorithm. As mentioned before, functional and dysfunctional questions should not be asked successively, but in random way. This randomization is the one of the improvement of this study. Also, the rank of choices should be randomized in every question, too. These changes make people to be more careful during the answering period.

2.3.2.3. Step 3: Evaluation of Kano Questionnaire. Once all the Kano questionnaires for a survey have been collected, designers tabulates them by looking up the classification of each customer needs in the Kano evaluation table which is shown at Table 1.5.

For a single attribute, all results are checked according to evaluation table. It is done by looking the intersection cell of functional and dysfunctional form of questions. When all inputs are tabulated, typically the most frequently observed Kano category is assigned to that customer requirement. At this point, one should ask oneself whether there is really a statistically significant difference between the most frequently observed category and the second one. According to [50], the products and service attributes are dynamic, thus successive service attributes follow the life cycles which start with indifferent attributes, then continue with attractive attributes, and then one-dimensional attributes and then must-be attributes, respectively. When any product introduces into a market, often an attribute may not be very interesting for the customers. They feel indifferent regarding to a new feature. In the growth phase of a market, the attribute may gain the ability to make customers feel satisfied, but they feel neutral if the feature does not exist. However, customers who frequently use that service including attractive attributes will be very dissatisfied if it disappears after a time. After a frequent time, those types of requirement are changed to the one-dimensional category. With same analogy, later on this attributes can be seen as basic requirements [25]. Therefore, at the transition periods, most of time there is no statistically significant difference between two successive categories.

In the previous model, the model uses crisp values for the Kano model for all categories, and most frequent attribute is chosen for the classification of the customer expectation, however, frequencies of others attributes may be very close and even not be statistically significant. Fuzzy logic theory is very suitable for this kind of conflicts, due to the acceptance of partial membership of two categories with different degrees. By using the FLT, one customer expectations can be thought as member of more than one cluster. For the application of the fuzzy logic theory, one of the membership functions which were explained in the introduction part can be chosen. In this study just the triangular membership function is used as an example. For the fuzzy membership functions, triangular MF which has same values at the center points with the crisp values using in the first model is chosen. Intersection areas are arbitarily accepted as 0.1 for all clusters. It can be increased or decreased by the researcher. Thus the triangular MF (Table 2.3) and representative Figure 2.1 can be seen as follows for the Kano model classification:

2.3.2.4. Step 4: Determining the Adjustment Factors for each Customer Requirements.

Calculations of adjustment factor for each customer attribute are same as the first model. Firstly satisfaction degree (SI) which shows how much the influence on cus-

Table 2.3. Fuzzy Logic variables and values for Kano Model classifications.

Linguistic Variables	**Fuzzy Numbers**
Indifference Attributes	(0;0;0.3)
Must-Be Attributes	(0.2;0,5;0.8)
One dimensional Attributes	(0.7;1;0;1,3)
Attractive Attributes	(1.2;1.5;1.8)

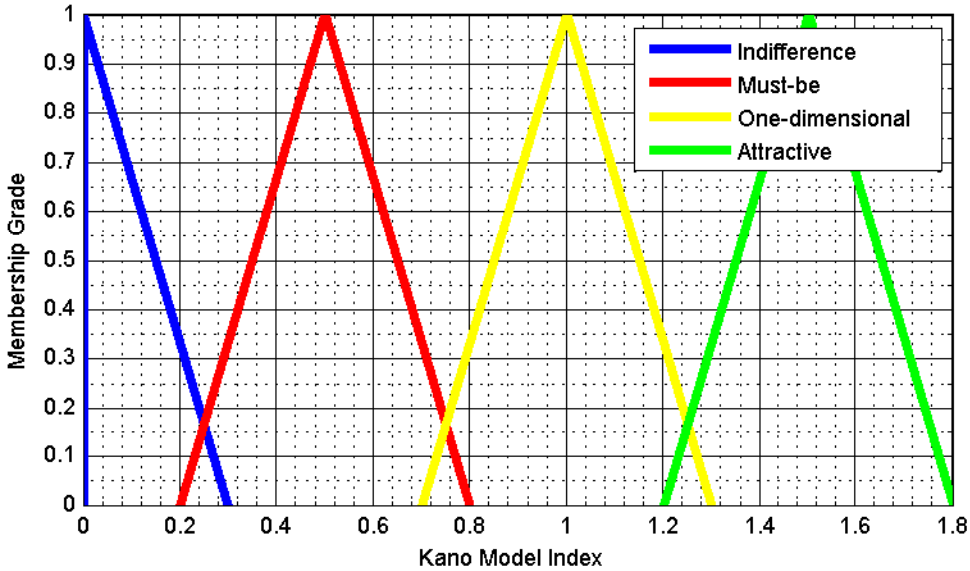

Figure 2.1. Triangular MF of Kano Model Classification.

tomer satisfaction is increased by providing a particular customer attribute, whereas dissatisfaction degree (DI) which indicates how much the influence on customer satisfaction is decreased by not providing that customer requirement should be calculated and then, their maximum value of SI and absolute value of DI should be evaluated in order to get adjustment factor. They can be found by following equations:

$$SI = \frac{f_{\mathrm{A}} + f_{\mathrm{O}}}{f_{\mathrm{A}} + f_{\mathrm{O}} + f_{\mathrm{M}} + f_{\mathrm{I}}} \tag{2.22}$$

$$DI = -\frac{f_{\mathrm{M}} + f_{\mathrm{O}}}{f_{\mathrm{A}} + f_{\mathrm{O}} + f_{\mathrm{M}} + f_{\mathrm{I}}} \tag{2.23}$$

where f_{A}, f_{O}, f_{M},, and f_{I} are ffrequency of attractive requirement, frequency of one-dimensional requirement, frequency of must-be requirements and frequency of indifference requirements respectively.According to satisfaction and dissatisfaction degrees, it is tried to understand which condition (product including or not including that attribute) has more influence on customers' purchase on product or service. With the help of dissatisfaction and satisfaction levels, adjustment factors for all needs are calculated as follows:

$$m = max\{SI, |DI|\} \tag{2.24}$$

where, m indicates the adjustment factor for the customer attributes.

2.3.2.5. Step 5: Determining the Importance of Customer Requirements . For each customer requirement, the significance level should be determined by the designer team for understanding how much the requirements are really important for them. In this point, second fuzzy sets are used in the new model. Instead of crisp values of 1, 2, 3, 4 and 5 for very low, low, medium, high and very high significance, the fuzzy sets are used for the five clusters. Again, triangular MFs which are more popular than other Ms in the literature are chosen. Also other types of the membership functions can be used. The upper and lower limits for all groups are listed in Table 2.4.

Table 2.4. Logic variables and values for importance of customer requirements.

Linguistic Variables	**Fuzzy Numbers**
Very Low	(1;1;2)
Low	(1;2;3)
Medium	(2;3;4)
High	(3;4;5)
Very High	(4;5.5)

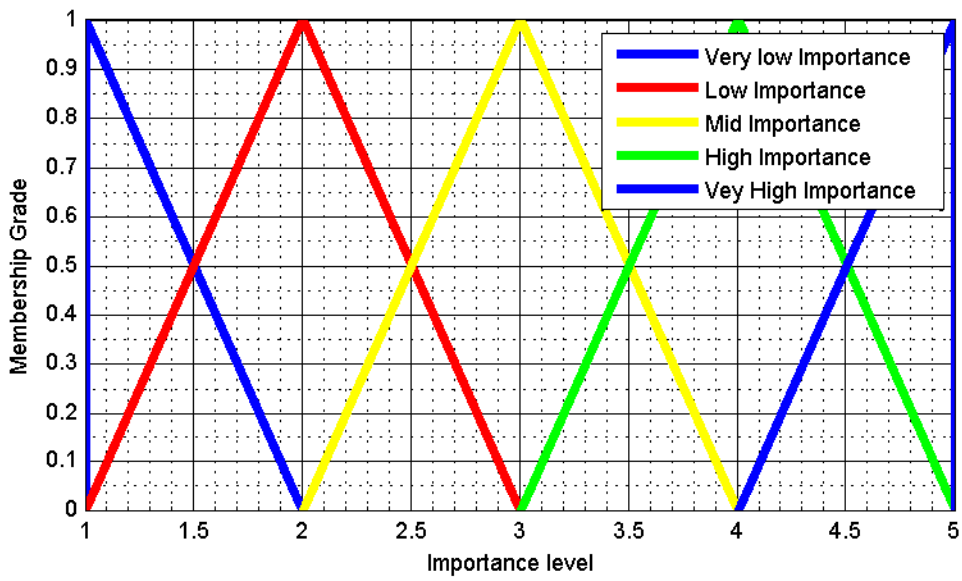

Figure 2.2. Triangular MF of Customer Attribute Significance.

2.3.2.6. Step 6: Analysis of Competitors and Setting Future Target . In today's competitive worlds, it is really important to follow what the competitors do, what they offer to the customers, and what kinds of different things they do in order to compete with them well. At least two competitors, one of which can be really good at that market and other can be average, should be analyzed to see various perspective. Therefore, learning the degree of their successes about all customer attributes should be really recommended. Moreover, this analysis also helps the designer to set the right future targets for all requirements.

Similar to competitor analysis, examining the circumstances of own company's product or service should be done by the designer teams. Awareness of both own product or service current conditions and competitors' conditions provides to set right future goals. When obtaining both current conditions and future targets, it is easy to calculate improvement ratio which is one of the multiplier of absolute weight formula of each attribute. Formula can be checked in Equation 2.25.

$$\text{improvement ratio (IR)} = \frac{\text{(future goal)}}{\text{(current customer satisfaction level)}} \tag{2.25}$$

2.3.2.7. Step 7: Sales Point Calculation of Customer Requirements: . In the literature, sales point values assist the companies to get competitive advantage, therefore, highest score is given to the requirement about the field that the company is better when comparing with other companies' conditions. On the other hand, if any requirement that the company does not have much capability for is scored as lowest value. Although, sales points do not carry as much weights as other factors such as importance of customers, or future goal, they should be considered as well due to the little effects on the sales quantities when performing the attributes well.

The proposed models bring a new approach to the traditional QFD model in determining the scoring the sales point value of each requirement. The simple connection between the sales point and Kano classification is that clusters like attractive requirement which provides more sales have high sales points whereas the classes like indifference attributes which do not provide extra sales gets lower sales points. The values are determined by the MF of Kano model. According to Table 2.3, the sales points can be matched with fuzzy sets of customer importance for each requirement. The only difference is that the calculations are done not only for core of MF but also upper and lower bounds of MF, too.

A new kind of calculation of sales point is proposed for the study. Firstly, the weights of the all clusters are calculated by dividing the frequency of each attribute with summation of the attractive, one-dimensional, must-be and indifference attribute frequencies. Following equation shows the way of calculation.

$$w_{\mathrm{j}} = \frac{f_{\mathrm{j}}}{f_{\mathrm{A}} + f_{\mathrm{O}} + f_{\mathrm{M}} + f_{\mathrm{I}}} \qquad (2.26)$$
$$j = A, O, \ldots, I$$

where w_{j} represents the weight of Kano cluster j and f_{j} represent frequency of Kano cluster j. Also, f_{A}, f_{O}, f_{M}, and f_{I}, indicate the frequency of attractive attribute, one-dimensional attribute, must-be attribute and indifference attribute, respectively.

Then, weights of every Kano cluster are multiplied with the corresponding Kano Model index in order to calculate the sales point of customer expectations. Kano index are assigned as 0, 0.5, 1 and 1.5 for indifference attribute, must-be attribute, one-dimensional attribute and attractive attribute, respectively. Next formula shows the calculation of sales points of n customer expectations.

$$SP_{\mathrm{i}} = w_{\mathrm{A}} \times k_{\mathrm{A}} + w_{\mathrm{O}} \times k_{\mathrm{O}} + w_{\mathrm{M}} \times k_{\mathrm{M}} + w_{\mathrm{I}} \times k_{\mathrm{I}} \qquad (2.27)$$
$$i = 1, 2, \ldots, n$$

where SP_{i} indicates sales point of customer expectation i. w_{A}, w_{O}, w_{M} and w_{I} shows weight of attractive attribute, one dimensional attribute, must-be attribute and indifference attribute, respectively. Similarly, k_{A}, k_{O}, k_{M} and k_{I} represents Kano model indices of attractive attribute, one dimensional attribute, must-be attribute and indifference attribute, respectively [23, 24].

2.3.2.8. Step 8: Calculation of Absolute and Relative Weights. The last calculations about the customer attributes are done to find their relative weights for the engineering specifications. Relative weights are nothing, but just the conversion of absolute weights to the percentage. Similar to the first model, normalized individual rating is recommended. Therefore, "1" is calculated for the most important customer attributes. And ratings of the others are decreasing successively till "0". The formulae are again showed in order to remind them.

$$\text{Absolute Weight} = (m_{\text{i}} \times \text{importance} \times IR_{\text{i}} \times \text{sales point}_{\text{i}}) \tag{2.28}$$

where m_{i} indicates the adjustment factor of customer requirement i, and IR_{i} shows improvement ratio of customer attribute i as indicates in the literature [1, 3].

$$\text{Relative weight} = \frac{(\text{absolute weight}_{\text{i}})}{(\text{maximum absolute weight})} \tag{2.29}$$

2.3.2.9. Step 9: Determining Engineering Specifications . Likewise the first model, the technical specifications which should be expressed with measurable units are listed in this part. In order to get right and reliable results, all technical specifications without any missing points should be listed.

2.3.2.10. Step 10: Determining the Relationship between What Lists and How Lists. The basic aim of QFD usage in the projects is to translate the customer languages to engineering languages which can be done at this part. The center of the HOQ is reserved for determining the relationships according to three clusters. To build the relationship matrix between the customer attributes and engineering specifications, it is necessary to establish whether or not a relationship exists between every "what" and every "how". All relationships are categorized either strong, medium or weak relationship. One of other new approach in the second proposed model is to prefer using the membership set values rather than the crisp values as used in the first model. Fuzzy set memberships are determined according to some previous studies about applications of integration of fuzzy logic and QFD [32]. [36] about the methodology of QFD with fuzzy approaches is recommended to read for better understanding. Same triangular MF, listed in Table 2.5 is used in this thesis.

Table 2.5. Fuzzy Logic variables and values for relationships between customer requirements and engineering specifications.

Linguistic Variables	**Fuzzy Numbers**
Weak Relationships	(0.0;0.2;0.4)
Medium Relationships	(0.3;0.5;0.7)
Strong Relationships	(0.6;0.8;1.0)

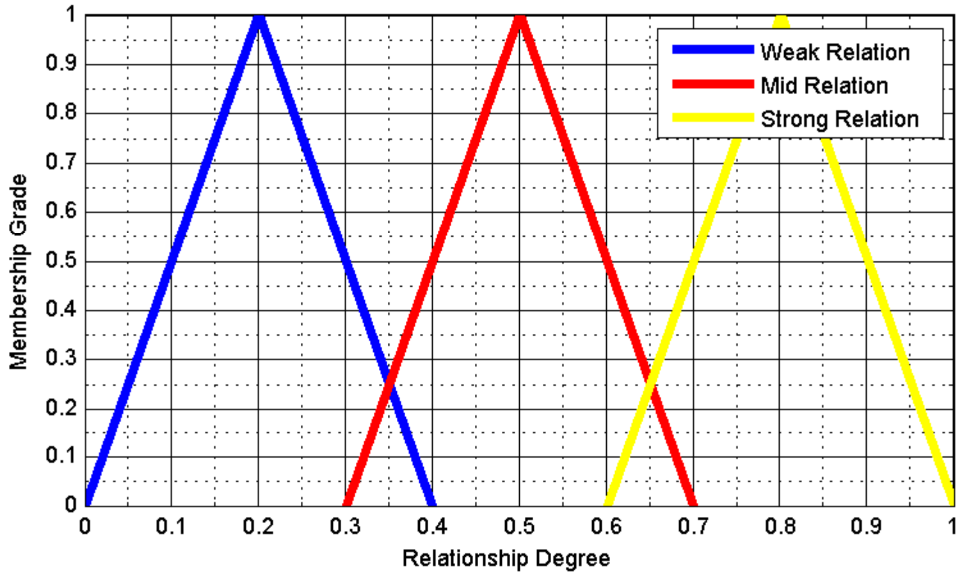

Figure 2.3. Triangular MF of Relationship Matrices.

2.3.2.11. Step 11: Calculations of Weights of Engineering Specifications . Absolute and relative weight calculations of engineering specifications are the next steps of the proposed model. Relative weights and relationship coefficients of what and how lists are two multipliers of the last calculations. Same formulae of the first models without any changes are used in the proposed model, too. If n customer requirements and m technical specification exist, then absolute weights of all m engineering specification are found as indicated in the literature:

$$\text{absolute weight}_{\text{z}} = \sum_{i=1}^{n} \text{relative weight of customer atribute}_{\text{i}} \times \text{relationship}_{\text{iz}} \quad (2.30)$$

where $i = 1, 2, \ldots, n$ and $z = 1, 2, \ldots, m$.

$$\text{relative weight}_{\text{z}} = \frac{\text{absolute weight}_{\text{z}}}{max(\text{absolute weight})} \quad (2.31)$$

2.3.2.12. Step 12: Defuzzification of Relative Weights. Defuzzification operations are the last step of the proposed model. After the relative weight calculations, all we have are a group of meaningless of values. It cannot be easy to interpret those, because there are lower boundaries, upper boundaries and cores. Therefore, defuzzification operation is chosen in order to get crisp values like first model and to interpret the results more easily.

In order to convert the fuzzy values to the crisp values, MATLAB can be proposed. A simple command, "defuzzy" can be used. For this command, three inputs are necessary. First one is the values of upper, lower and core values of fuzzy graph. Second input is the membership function of the fuzzy function. And lastly, type of defuzzification model is needed.

2.3.3. Comparison of the Proposed Model (Fuzzy Kano- Fuzzy QFD) and Existing Fuzzy Kano-QFD Models

In the literature, a few fuzzy Kano-QFD integration models exist. Generally Kano Models are used for updating the improvement ratio (IR) values. In our case, Kano Model is used for both calculating adjustment factor and sale points scoring. Comparison can be seen better in Table 2.6.

2.3.4. Comparison of the Two Proposed Models

Actually first model and second model have the same steps excepts defuzzification calculations of absolute customer and engineering specification weights in the second model, however values being used in the models make them different models and provide different results. In order to remind the steps and see the differences at the same time, a comparison table is prepared, see Table 2.7.

Table 2.6. Comparison of Existing Fuzzy Kano- Fuzzy-QFD Model and FKFQFD.

<table>
<tr><th>Steps</th><th>Existing Fuzzy Kano- Fuzzy QFD Models in the Literature</th><th>Proposed Model II: Fuzzy Kano- Fuzzy QFD (FK-FQFD))</th></tr>
<tr><td>Step 1</td><td>Determining customer expectations with market survey.</td><td>Determining customer expectations with market survey.</td></tr>
<tr><td>Step 2</td><td>Making Kano Questionnaire according to results of market survey.</td><td>Making Kano Questionnaire according to results of market survey. Here Kano Questionnaire and choices of the questions are listed in randomized manner which prevents biased error.</td></tr>
<tr><td>Step 3</td><td>Finding fuzzy weights of Kano Model indices [18].</td><td>Evaluation of Kano Questionnaire according to Kano Evaluation Table. Here, Kano model indexes are assigned by fuzzy values
<table><tr><td>Indifference Attributes</td><td>(0;0;0.3)</td></tr><tr><td>Must-Be Attributes</td><td>(0.2;0.5;0.8)</td></tr><tr><td>One dimensional Attributes</td><td>(0.7;1.0;1,3)</td></tr><tr><td>Attractive Attributes</td><td>(1.2;1.5;1.8)</td></tr></table>
Determining the adjustment factors (m) for each customer requirements.</td></tr>
</table>

Table 2.6. Comparison of Existing Fuzzy Kano- Fuzzy-QFD Model and FKFQFD(cont.).

Steps	**Existing Fuzzy Kano- Fuzzy QFD Models in the Literature**	**Proposed Model II: Fuzzy Kano- Fuzzy QFD (FKFQFD)**
		$SI = \frac{f_{\mathrm{A}}+f_{\mathrm{O}}}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, DI = -\frac{f_{\mathrm{M}}+f_{\mathrm{O}}}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, m = max\{SI, \lvert DI \rvert\}$
Step 4	Assigning the importance of customer expectations and analyzing the competitors' conditions.	Assigning the importance of customer expectations and analyzing the competitors' conditions.
Step 5	Analysis of competitors, setting future target and finding IR. $\text{improvement ratio (IR)} = \frac{\text{(future goal)}}{\text{(current customer satisfaction level)}}$ Adjustment ratio is updated by following ratio: $IR_{\mathrm{adj}} = (IR_0)^{(1/k)}$	Analysis of competitors, setting future target and finding IR. $\text{improvement ratio (IR)} = \frac{\text{(future goal)}}{\text{(current customer satisfaction level)}}$

Table 2.6. Comparison of Existing Fuzzy Kano- Fuzzy-QFD Model and FKFQFD(cont.).

Steps	**Existing Fuzzy Kano- Fuzzy QFD Models in the Literature**	**Proposed Model II: Fuzzy Kano- Fuzzy QFD (FK-FQFD)**
Step 6	Assigning the Sales Points (SP) of customer requirements. Generally, these values are determined by the marketing department of the company.	Sales point (SP) calculations of customer requirements. They are done by firstly calculating the weights of Kano Clusters and then finding the sales points. Calculations are done for upper bounds, core and lower bounds. $$w_j = \frac{f_j}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, j = A, O, \ldots, I$$ $$SP_{\mathrm{i}} = w_{\mathrm{A}} \times k_{\mathrm{A}} + w_{\mathrm{O}} \times k_{\mathrm{O}} + w_{\mathrm{M}} \times k_{\mathrm{M}} + w_{\mathrm{I}} \times k_{\mathrm{I}}, i = 1, 2, \ldots, n$$
Step 7	Calculation of absolute and relative weights of customer requirements. $$\text{Absolute Weight} = (m_{\mathrm{i}} \times \text{importance} \times IR_{\mathrm{i}} \times \text{sales point}_{\mathrm{i}})$$	Calculation of absolute and relative weights of customer requirements. $$\text{Absolute Weight} = (m_{\mathrm{i}} \times \text{importance} \times IR_{\mathrm{i}} \times \text{sales point}_{\mathrm{i}})$$

Table 2.6. Comparison of Existing Fuzzy Kano- Fuzzy-QFD Model and FKFQFD(cont.).

Steps	**Existing Fuzzy Kano- Fuzzy QFD Models in the Literature**	**Proposed Model II: Fuzzy Kano- Fuzzy QFD (FKFQFD)**
	$\text{Relative weight} = \frac{(\text{absolute weight}_i)}{(\text{maximum absolute weight})}$	$\text{Relative weight} = \frac{(\text{absolute weight}_i)}{(\text{maximum absolute weight})}$
Step 8	Determining engineering specifications.	Determining engineering specifications.
Step 9	Determining the relationship between What Lists and How Lists. Here relationships are assigned by crisp values. Weak Relationship: 1 Moderate Relationship: 3 Strong Relationship: 5	Determining the relationship between What Lists and How Lists. Here relationships are assigned by fuzzy values. Weak Relationship: (0.0;0.2;0.4) Moderate Relationship: (0.3;0.5;0.7) Strong Relationship: (0.6;0.8;1;0)
Step 10	Calculations of absolute and relative weights of engineering specifications.	Calculations of absolute and relative weights of engineering specifications.

Table 2.6. Comparison of Existing Fuzzy Kano- Fuzzy-QFD Model and FKFQFD(cont.).

Steps	**Existing Fuzzy Kano- Fuzzy QFD Models in the Literature**	**Proposed Model II: Fuzzy Kano- Fuzzy QFD (FK-FQFD)**
	$\text{absolute weight}_\text{z} =$ $\sum_{i=1}^{n} \text{relative weight of customer atribute}_\text{i} \times \text{relationship}_\text{iz}$ where $i = 1, 2, \ldots, n$ and $z = 1, 2, \ldots, m$. $\text{relative weight}_\text{z} = \frac{\text{absolute weight}_\text{z}}{max(\text{absolute weight})}$	$\text{absolute weight}_\text{z} =$ $\sum_{i=1}^{n} \text{relative weight of customer atribute}_\text{i} \times \text{relationship}_\text{iz}$ where $i = 1, 2, \ldots, n$ and $z = 1, 2, \ldots, m$. $\text{relative weight}_\text{z} = \frac{\text{absolute weight}_\text{z}}{max(\text{absolute weight})}$

Table 2.7. Comparison of KQFD and FKFQFD.

<table>
<tr><th>Steps</th><th>Proposed Model 1: Modified Kano-QFD (MKQFD)</th><th>Proposed Model 2: Fuzzy Kano & Fuzzy QFD (FK-FQFD))</th></tr>
<tr><td>Step 1</td><td>Determining customer expectations with market survey.</td><td>Determining customer expectations with market survey.</td></tr>
<tr><td>Step 2</td><td>Making Kano Questionnaire according to results of market survey. Here Kano Questionnaire and choices of the questions are listed in randomized manner which prevents biased error.</td><td>Making Kano Questionnaire according to results of market survey. Here Kano Questionnaire and choices of the questions are listed in randomized manner which prevents biased error.</td></tr>
<tr><td>Step 3</td><td>Evaluation of Kano Questionnaire according to Kano Evaluation Table. Here, Kano model indexes are assigned by crisp values.
<table><tr><td>Indifference Attributes</td><td>0</td></tr><tr><td>Must-Be Attributes</td><td>0.5</td></tr><tr><td>One dimensional Attributes</td><td>1</td></tr><tr><td>Attractive Attributes</td><td>1.5</td></tr></table></td><td>Evaluation of Kano Questionnaire according to Kano Evaluation Table. Here, Kano model indexes are assigned by fuzzy values
<table><tr><td>Indifference Attributes</td><td>(0;0;0.3)</td></tr><tr><td>Must-Be Attributes</td><td>(0.2;0.5;0.8)</td></tr><tr><td>One dimensional Attributes</td><td>(0.7;1.0;1,3)</td></tr><tr><td>Attractive Attributes</td><td>(1.2;1.5;1.8)</td></tr></table></td></tr>
<tr><td>Step 4</td><td>Determining the adjustment factors (m) for each customer requirements.</td><td>Determining the adjustment factors (m) for each customer requirements.</td></tr>
</table>

Table 2.7. Comparison of KQFD and FKFQFD(cont.).

Steps	**Proposed Model 1: Modified Kano-QFD (MKQFD)**	**Proposed Model 2: Fuzzy Kano & Fuzzy QFD (FK-FQFD))**
	$SI = \frac{f_{\mathrm{A}}+f_{\mathrm{O}}}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, DI = -\frac{f_{\mathrm{M}}+f_{\mathrm{O}}}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, m = max\{SI, \|DI\|\}$	$SI = \frac{f_{\mathrm{A}}+f_{\mathrm{O}}}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, DI = -\frac{f_{\mathrm{M}}+f_{\mathrm{O}}}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, m = max\{SI, \|DI\|\}$
Step 5	Determining the importance of customer requirements. Here importance values are assigned by crisp values. Very Low: 1 Low: 2 Medium: 3 High: 4 Very High: 5	Determining the importance of customer requirements. Here importance values are assigned by fuzzy values. Very Low: 1 Low: 2 Medium: 3 High: 4 Very High: 5
Step 6	Analysis of competitors, setting future target and finding IR.	Analysis of competitors, setting future target and finding IR.

Table 2.7. Comparison of KQFD and FKFQFD(cont.).

Steps	**Proposed Model 1: Modified Kano-QFD (MKQFD)**	**Proposed Model 2: Fuzzy Kano & Fuzzy QFD (FK-FQFD))**
	improvement ratio (IR) $= \frac{\text{(future goal)}}{\text{(current customer satisfaction level)}}$	improvement ratio (IR) $= \frac{\text{(future goal)}}{\text{(current customer satisfaction level)}}$
Step 7	Sales point (SP) calculations of customer requirements. They are done by firstly calculating the weights of Kano Clusters and then finding the sales points. $w_j = \frac{f_j}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, j = A, O, \ldots, I$ $SP_{\mathrm{i}} = w_{\mathrm{A}} \times k_{\mathrm{A}} + w_{\mathrm{O}} \times k_{\mathrm{O}} + w_{\mathrm{M}} \times k_{\mathrm{M}} + w_{\mathrm{I}} \times k_{\mathrm{I}}, i = 1, 2, \ldots, n$	Sales point (SP) calculations of customer requirements. They are done by firstly calculating the weights of Kano Clusters and then finding the sales points. Here the only differences are to make all calculations not only for core values but also for upper and lower bounds, as well. $w_j = \frac{f_j}{f_{\mathrm{A}}+f_{\mathrm{O}}+f_{\mathrm{M}}+f_{\mathrm{I}}}, j = A, O, \ldots, I$ $SP_{\mathrm{i}} = w_{\mathrm{A}} \times k_{\mathrm{A}} + w_{\mathrm{O}} \times k_{\mathrm{O}} + w_{\mathrm{M}} \times k_{\mathrm{M}} + w_{\mathrm{I}} \times k_{\mathrm{I}}, i = 1, 2, \ldots, n$

Table 2.7. Comparison of KQFD and FKFQFD(cont.).

Steps	Proposed Model 1: Modified Kano-QFD (MKQFD)	Proposed Model 2: Fuzzy Kano & Fuzzy QFD (FK-FQFD))
Step 8	Calculation of absolute and relative weights of customer requirements. $\text{Absolute Weight} = (m_{\text{i}} \times \text{importance} \times IR_{\text{i}} \times \text{sales point}_{\text{i}})$ $\text{Relative weight} = \frac{(\text{absolute weight}_{\text{i}})}{(\text{maximum absolute weight})}$	Calculation of absolute and relative weights of customer requirements. Here, the differences occur due to doing all calculations for core, upper, and lower bounds. $\text{Absolute Weight} = (m_{\text{i}} \times \text{importance} \times IR_{\text{i}} \times \text{sales point}_{\text{i}})$ $\text{Relative weight} = \frac{(\text{absolute weight}_{\text{i}})}{(\text{maximum absolute weight})}$
Step 9	Determining engineering specifications.	Determining engineering specifications.
Step 10	Determining the relationship between What Lists and How Lists. Here relationships are assigned by crisp values.	Determining the relationship between What Lists and How Lists. Here relationships are assigned by fuzzy values.

Table 2.7. Comparison of KQFD and FKFQFD(cont.).

Steps	Proposed Model 1: Modified Kano-QFD (MKQFD)	Proposed Model 2: Fuzzy Kano & Fuzzy QFD (FK-FQFD))
	Weak Relationship: 1 Moderate Relationship: 3 Strong Relationship: 5	Weak Relationship: (0.0;0.2;0.4) Moderate Relationship: (0.3;0.5;0.7) Strong Relationship: (0.6;0.8;1;0)
Step 11	Calculations of absolute and relative weights of engineering specifications. $\text{absolute weight}_{\text{z}} = \sum_{i=1}^{n} \text{relative weight of customer atribute}_{\text{i}} \times \text{relationship}_{\text{iz}}$ where $i = 1, 2, \ldots, n$ and $z = 1, 2, \ldots, m$. $\text{relative weight}_{\text{z}} = \frac{\text{absolute weight}_{\text{z}}}{max(\text{absolute weight})}$	Calculations of absolute and relative weights of engineering specifications. Here, the differences occur due to doing all calculations for upper, core and lower bounds. $\text{absolute weight}_{\text{z}} = \sum_{i=1}^{n} \text{relative weight of customer atribute}_{\text{i}} \times \text{relationship}_{\text{iz}}$ where $i = 1, 2, \ldots, n$ and $z = 1, 2, \ldots, m$. $\text{relative weight}_{\text{z}} = \frac{\text{absolute weight}_{\text{z}}}{max(\text{absolute weight})}$
Step 12		Defuzzification of relative weights of engineering specifications.

3. CASE STUDY: AN ERGONOMIC KETTLE DESIGN

The human hand is a beautifully designed organ, capable of an infinite variety of configurations and functions. Unfortunately, due to the repeated daily activities, such as holding a hand-used product or spending higher effort for pushing or pulling any product, people often require certain types of manual exertion that can cause a progressive deterioration of support tissues, muscles and nerve resulting in discomfort, pain and loss of function. Moreover, tool design like hand-used product with a handle, which does not fit with ergonomic design criteria, leads to cumulative trauma to the musculoskeletal systems of upper extremity, particularly the hand and wrist tissues. Therefore, good hand tool design and handle design are important at work and in all kinds of daily activities for items that are efficient to use, safe and attractive to buy [51, 52].

Anything that can be picked up by the human hand or which the body comes in contact with it is in some sense a handle which are generally have same unexpected features and troubles. Small or stiff or sharp or awkwardly placed handles lead to confusing for usage. Despite the change in the society from an industrial base, and from human to machine power, human stills communicate with products by applying their hands or fingers. Thus, ergonomic design criteria should be considered at the beginning of the every design stage of hand-used products/tools to reduce stress and fatigue and eventually, to protect the human from cumulative trauma on the upper extremities. The result of ignoring of ergonomics, perhaps realizing after many years, leads to high injuries and illnesses which reduce the productivity of both human and companies [52].

The simple act of gripping a handle to support the product can suggest the desirable thickness, length and position, however, individuals may apply different grip forces and assume different postures according to their habit, size and product. The problem of allowing for various grips can be solved by designing handles to different users by taking into account the anthropometric measurements of population where the product is planned to sell.

In this study, to illustrate the proposed models, ergonomic design criteria of the kettle are selected as a case study. Required engineering specifications for ergonomic kettle designs which meet customer needs and expectations are determined by using quality approaches of QFD, Kano Model and FL. This part continues as follows: In Section 3.2, first proposed mode (MKQFD), just combining Kano Model and QFD, will be applied to the case study while explaining all steps in detail. In Section 3.2, the application of the proposed fuzzy Kano and fuzzy QFD model (FKFQFD) and its results will be explained.

3.1. Proposed Model 1: Modified Kano-QFD Model (MKQFD)

In this part, calculations of proposed model I (MKQFD) is explained step by step. All results are showed both in the tables and HOQ.

3.1.1. Step 1: Determination of Customer Expectations

First step of proposed model is to find the customer expectations and needs about the kettles. For this purpose, some basic questions are asked to 100 possible final users and their answers are examined for determining the Kano model questionnaire. Basic information about the subjects is listed in Table 3.1.

Table 3.1. Information about the subjects in market survey I.

TITLE	MALE	FEMALE
Number of subjects	54	46
Average Height	1.79	1.67
Average Weight	90	63
Average Age	28	26

Some example questions are listed at below.

(i) What kinds of features do you expect from the kettle?
(ii) What kinds of features did you get from your current kettle?
(iii) What kinds of complaints do you have from your current kettle?
(iv) When you compare the products of different companies, which features do you mostly concentrated on?

Various types of needs and expectations about design parameters, material specifications, electrical components, energy efficiency are obtained from the subjects. Some expectations were in conflict with each other, or some of them were very irrelevant with the purpose of the study. Therefore, in order to get rid of unnecessary knowledge and see whole picture about customer expectations about ergonomic kettle design, results of customer survey is classified according to five relevant topic about the kettle:

(i) Expectations about brand and price,
(ii) Expectations about design parameters,
(iii) Expectations about electrical parts,
(iv) Expectations about materials
(v) Expectations about energy efficiency.

Table 3.2 shows this classification of market survey. According to those, what lists that included 18 items were determined.

After listing all customer expectations obtained from market survey, the ones that are related with ergonomic design are selected, and what lists are established. Table 3.3 shows these items.

Table 3.2. Classification of customer survey about Kettle Design.

Expectations from Brand and Price	**Expectations from Design Parameters**	**Expectations from Electrical Partsches**	**Expectations from Materials**	**Expectations from Energy Efficiency**
It should be produced by a reputable company.	It should be easy to clean.	It should shut down automatically, after boiling.	It should be manufactured by high quality materials.	The boiling duration should be short.
It should have affordable price.	The clearance between the handle and kettle body should be adequate so that fingers are comfortable.	Kettle should have a warning signal to indicate boiling.	The handle should be covered by material that comforts the hand and wrist while holding the kettle.	Kettle should not require minimum amount of water to start heating.
It should have long warranty period.	It should have a section at the bottom for hiding the power cord.	It should operate both with and without power cord.	Kettle should be manufactured by easily cleanable material.	It should restart to heat the water after the temperature of water drops to a specific degree. (it should have a thermostat.
It should have easily attainable technical service.	It should not stress the wrist while holding.	It should have hidden resistance for easy clean.	The lid should be made of durable material.	It should be energy efficient.
	The lid should easily be opened.	It should have a warning light to indicate it is on.	The on/off button should be made of durable material.	Heat loss should be low.
	It should have water level indicator.	Calcification periods of resistance should be long.	The power cord should not be very long.	
	It should have an aesthetic design.		It should have light weight.	
	It should have high water volume capacity.		The surface materials should be tough.	
	Water should not drip from the body surface.			

Table 3.2. Classification of customer survey about kettle design (cont.).

Expectations from Brand and Price	**Expectations from Design Parameters**	**Expectations from Electrical Partsches**	**Expectations from Materials**	**Expectations from Energy Efficiency**
	It should have a filter on the spout of kettle.			
	It should have circular base.			

Table 3.3. What Lists of QFD.

Item number	**What Lists / Customer Expectations**
Item1	Kettle should not require minimum amount of water to start heating.
Item 2	Heat loss should be minimal.
Item 3	Kettle should shut down automatically, after boiling. (It should have a thermostat)
Item 4	Kettle should have warning signal to indicate boiling.
Item 5	Kettle should have a indicator light which shows it is working.
Item 6	Handle of kettle should have a comfortable design which does not strain the hand, wrist and arm while being used.
Item 7	Kettle should have an additional division on the bottom part for hiding the power cord.
Item 8	The base of the kettle should be circular in order to put the kettle on it from all directions.
Item 9	The kettle should be cleaned easily.
Item 10	Kettle should have a hidden resistance for easy clean.
Item 11	Kettle should have a water level indicator.
Item 12	While pouring the water, water should not drip from the surface of body.
Item 13	The lid of kettle should be opened easily.
Item 14	Kettle should be made of high quality material.
Item 15	The clearance between the kettle body and handle should not discomfort the fingers of the users.
Item 16	Kettle should have a light weight.
Item 17	The handle of kettle should not be very big.
Item 18	The handle of kettle should be covered by non-slippery material in order to prevent sliding and comfortable handling.

3.1.2. Step 2: Making Kano Questionnaire

Kano questionnaire consists of two types of questions (positive and negative types) for each customer expectations. Positive questions for a particular attribute, also named as functional questions, tries to measure customer response if the product or service includes that certain attribute. On the other hand, dysfunctional question is asked to describe the user reaction if the opposite scenario is performed. Thus, totally 36 questions are prepared for 18 customer expectations. Also 5 other questions about the gender, weight, height, age and occupation of the subjects are asked for making statistical inferences. On Table 3.4, functional and dysfunctional questions for the eleventh item are shown as an example. The actual Kano questionnaire both in Turkish and English versions that consists of 41 questions can be found in Appendix A.

Table 3.4. Functional and dysfunctional questions for the eleventh customer requirement.

Questions	Possible Responses
1. If the kettle is shut down automatically after boiling, how do you feel?	1. I like it that way 2. It must be that way 3. I am neutral 4. I can live with it that way 5. I dislike it that way
2. If the kettle is not shut down automatically after boiling, how do you feel?	1. I like it that way 2. It must be that way 3. I am neutral 4. I can live with it that way 5. I dislike it that way

As mentioned before, the orders of questions and the answers are asked by randomized manner in the questionnaire in order to get unbiased answers.

This questionnaire was the second market survey. And totally 81 people complete these questionnaire. 43 of them are female and 38 of them are male. Average age of female is 32.2 whereas it is 36 for male. 176.7 cm and 84.3 kg are the male's average height and average weight, respectively. For females these values are 166.7 cm and 62.6 kg, respectively. Table 3.8 shows the summary of subject information. Moreover, subjects from very different job sector are selected in order to include different user population. Engineers, research assistances, planners, blue-collar workers, housewives, students, technicians, retired people etc. are the participants of this questionnaire.

Table 3.5. Information about the subjects in market survey II.

TITLE	**MALE**	**FEMALE**
Number of subjects	38	43
Average Height	1.76	1.66
Average Weight	84.2	62.6
Average Age	36	22

3.1.3. Step 3: Evaluation of Kano Questionnaire

In this part, the responses to each pair of functional and dysfunctional questions are examined according to Kano evaluation table. For each customer requirement, responses of all subjects are classified according to determined Kano cluster frequencies. For example, if subject 1 answers the functional question of any item as “It must be that way” and answered the dysfunctional question of this item as “I dislike it that way”, then it becomes a reverse requirements for subject 1. Obtaining the classification is very simple procedure. One should only record the letter in the intersection cell of the Kano evaluation table. Table 3.6 shows the responses of subject 1’s questionnaire and corresponding Kano cluster results.

Following this procedure, all responses of all subjects are documented. 3.7 shows the frequencies of all customer expectations.

Table 3.6. Example of evaluation of functional and dysfunctional questions by Kano Evaluation Table.

What Lists	**Answer of Functional Questions**	**Answer of Dysfunctional Question**	**Kano Cluster**
Item 1	It must be that way.	It must be that way.	I
Item 2	I like it that way.	I dislike it that way.	O
Item 3	I like it that way.	I like it that way.	Q
Item 4	I like it that way.	I am neutral.	A
Item 5	I like it that way.	I dislike it that way.	O
Item 6	I like it that way.	I dislike it that way.	O
Item 7	I like it that way.	I like it that way.	Q
Item 8	I like it that way.	I dislike it that way.	O
Item 9	I like it that way.	I dislike it that way.	O
Item 10	It must be that way.	I can live it that way.	I
Item 11	It must be that way.	I dislike it that way.	M
Item 12	I like it that way.	I dislike it that way.	O
Item 13	I like it that way.	I dislike it that way.	O
Item 14	It must be that way.	I dislike it that way.	M
Item 15	I like it that way.	I dislike it that way.	O
Item 16	I like it that way.	I dislike it that way.	O
Item 17	I dislike it that way.	I am neutral.	R
Item 18	I dislike it that way.	I can live it that way.	R

Table 3.7. Kano Classification of What Lists.

Item number	**Attractive Attribute**	**One-Dimensional Attribute**	**Must-Be Attribute**	**Indifference Attribute**	**Reversible Attribute**	**Questionable Attribute**	**Kano Classification**
1	9	0	1	45	24	2	I
2	14	47	13	5	1	1	O
3	5	25	36	8	4	3	M
4	29	6	5	35	2	4	I
5	5	20	39	10	3	4	M
6	8	39	18	10	2	4	O
7	23	11	16	27	2	2	I
8	21	14	13	28	3	2	I
9	14	39	16	10	1	1	O
10	15	14	23	26	2	1	I
11	5	12	34	28	0	2	M
12	3	25	41	5	1	6	M
13	1	32	27	17	2	2	O
14	10	36	21	11	2	1	O
15	7	30	18	23	1	2	O

Table 3.7. Kano Classification of What Lists(cont.)

Item number	**Attractive Attribute**	**One-Dimensional Attribute**	**Must-Be Attribute**	**Indifference Attribute**	**Reversible Attribute**	**Questionable Attribute**	**Kano Classification**
16	6	26	10	35	4	0	I
17	1	4	5	51	16	4	I
18	10	20	17	31	1	2	I

3.1.4. Step 4: Determining the Adjustment Factors for each Customer Requirements

In this part, the frequencies of each requirement which had been calculated in previous section are used to determine the satisfaction and dissatisfaction indexes. Formulae of 2.12 and 2.13 are used for the calculations. Finally, the maximum absolute value of SI or DI of certain attribute (adjustment factor) is assigned to that requirement according to Equation 2.14. Table 3.9 shows the frequencies of Kano clusters, SI, DI of each attributes and final assigned adjustment factors. Example calculations for item 1 are written at below.

Table 3.8. Values that are used for calculation of SI_1 & DI_1.

Frequency of attractive attribute	9
Frequency of one-dimensional attribute	0
Frequency of must-be attribute	1
Frequency of indifference attribute	45
Frequency of reverse attribute	24
Frequency of questionable attribute	2

$$SI_1 = \frac{f_{\mathrm{A}} + f_{\mathrm{O}}}{f_{\mathrm{A}} + f_{\mathrm{O}} + f_{\mathrm{M}} + f_{\mathrm{I}}} = \frac{9+0}{9+0+1+45} = 0.16$$

$$DI_1 = -\left(\frac{f_{\mathrm{M}} + f_{\mathrm{O}}}{f_{\mathrm{A}} + f_{\mathrm{O}} + f_{\mathrm{M}} + f_{\mathrm{I}}}\right) = -\left(\frac{1+0}{9+0+1+45}\right) = -0.02$$

$$m = max\{SI, |DI|\} = max\{0.16, |-0.02|\} = 0.16$$

Table 3.9. Kano Classification of What Lists.

Item number	**Attractive Attribute**	**One-Dimensional Attribute**	**Must-Be Attribute**	**Indifference Attribute**	**Reversible Attribute**	**Questionable Attribute**	**Kano Classification**	**Satisfaction Index (SI)**	**Dissatisfaction Index (DI)**	**Adjustment Factor (m)**
1	9	0	1	45	24	2	I	0.16	-0.02	0.16
2	14	47	13	5	1	1	O	0.77	-0.76	0.77
3	5	25	36	8	4	3	M	0.41	-0.82	0.82
4	29	6	5	35	2	4	I	0.47	-0.15	0.47
5	5	20	39	10	3	4	M	0.34	-0.8	0.8
6	8	39	18	10	2	4	O	0.63	-0.76	0.76
7	23	11	16	27	2	2	I	0.44	-0.35	0.44
8	21	14	13	28	3	2	I	0.46	-0.36	0.46
9	14	39	16	10	1	1	O	0.67	-0.7	0.7
10	15	14	23	26	2	1	I	0.37	-0.47	0.47
11	5	12	34	28	0	2	M	0.22	-0.58	0.58
12	3	25	41	5	1	6	M	0.38	-0.89	0.89
13	1	32	27	17	2	2	O	0.43	-0.77	0.77
14	10	36	21	11	2	1	O	0.59	-0.73	0.73
15	7	30	18	23	1	2	O	0.47	-0.62	0.62

Table 3.9. Kano Classification of What Lists(cont.).

Item number	**Attractive Attribute**	**One-Dimensional Attribute**	**Must-Be Attribute**	**Indifference Attribute**	**Reversible Attribute**	**Questionable Attribute**	**Kano Classification**	**Satisfaction Index (SI)**	**Dissatisfaction Index (DI)**	**Adjustment Factor (m)**
16	6	26	10	35	4	0	I	0.42	-0.47	0.47
17	1	4	5	51	16	4	I	0.08	-0.15	0.15
18	10	20	17	31	1	2	I	0.38	-0.47	0.47

3.1.5. Step 5: Determining the Importance of Customer Requirements

In the previous steps, the importance of customer requirements was found according to the customers' point of view, however in this step, the designer team (here, they are I and my advisor) grades them. In the first proposed method, the crisp values are used for the calculations. 5, 4, 3, 2, 1 are assigned to very high, high, medium, low and very low importance, respectively. In Table 3.10, you can see the assigned importance levels and assigned importance values.

As mentioned in Section 3.1.1, the customer expectations are listed according to ergonomic design criteria. Thus significance ratings are given according to ergonomic importance. And most related ones are assigned as very high importance. Item 6 (handle kettle should have a comfortable design which does not strain the hand, arm and wrist.), and item 15 (the clearance between the kettle body and handle should not discomfort the user fingers.) are exactly related with ergonomic design considerations. Therefore they are assigned as "very high important customer expectations". Also item 14 (the quality of the kettle materials should be good.) is about quality and human issues. Thus it is also assigned as "very high significant customer need". Lastly item 12 (while pouring the water, water should not drip from the surface of body.) is seen as "very high significant customer expectations", because undesirable water flowing from the surface is really bothersome. On the other hand, item 1 (kettle should not require minimum amount of water into the kettle before heating.), item 2 (heat loss should be minimal.), item 3 (after boiling, kettle should shut down automatically.), item 9 (kettle should have an easily cleanable design), item 11 (kettle should have a water level indicator), and item 18 (the handle of kettle can be covered by a material in order to prevent sliding) are assigned as "high important customer needs", because they satisfy customers but they cannot think as a major needs. Item 5 (Kettle should have a warning light which shows it is working.), item 8 (The base of the kettle should be circular in order to put the kettle on it from all ways.), item 10 (Kettle should have a water level indicator.), item 13 (The lid of kettle should be opened easily.) and item 16 (Kettle should have a light weight.) are assigned as "middle important customer specifications" due to the not exactly relating with ergonomic design parameters and

Table 3.10. The importance of customer requirement according to designer point of view.

Item Number	**Importance**	**Rate of Importance**	**Reason**
1	H	4	It satisfies the customers but it is not a major need.
2	H	4	It satisfies the customers but it is not a major need.
3	H	4	It satisfies the customers but it is not a major need.
4	L	2	It is not a priority need.
5	MI	3	It is a secondary design issue.
6	VH	5	It is about ergonomic design criteria.
7	VL	1	It is the least significant design issue.
8	MI	3	It is a secondary design issue.
9	H	4	It satisfies the customers but it is not a major need.
10	MI	3	It is a secondary design issue.
11	H	4	It satisfies the customers but it is not a major need.
12	VH	5	It is about ergonomic design criteria.
13	MI	3	It is a secondary design issue.
14	VH	5	It is about ergonomic design criteria.
15	VH	5	It is about quality and health issues.
16	MI	3	It is a secondary design issue.
17	L	2	It is not a priority need.
18	H	4	It satisfies the customers but it is not a major need.

working principles. They can be thought as secondary design parameters. They just provide some facility to the users. Furthermore, item 4 (Kettle should warn loudly after boiling.) and item 17 (The handle of kettle should not be very big.) are just specific desires for some of the users. For many customers they are not priority needs. Likewise the customers, we assign them as “low significant customer specifications”. And lastly, item 7 (Kettle can have an additional division on the bottom part for hiding the cable.) was assigned as “very low important customers need”.

3.1.6. Step 6: Analysis of Competitors and Setting Future Target

In order to examine the market and analyze the competitors’ conditions, two brands, Arçelik and Veito are chosen. Because our product is new in the household goods market, it is seen as okay to analyze one brand which is one of best in its sector, and one which is not a well-known brand in its sector. Therefore, Arçelik is selected because it is seen as a leader in household goods sector and for unknown name, Veito is chosen. In this part, grading the attributes is done by designer team and the results are listed at Table 3.11.

For the newest companies in any sector, the most significant thing is to determine the aim of company. Most of time, the reason behind the failure of any company is wrong and unreasonable targets. Therefore, investigating all competitors in the sector is the crucial step of setting the right target. For this reason, our aim is to produce better kettle than Veito and to do our best to manufacture a kettle as Arçelik’s. Because we are at the beginning of the design stage and because we do not have any kettle, the achievement levels of all customer requirements are assigned as 1, very low. At Table 3.11, the targets of each requirement are listed, as well. Also, the improvement ratio value of all requirements which are calculated according to Eqaution 2.25 can be seen in Table 3.11.

$$\text{improvement ratio (IR)} = \frac{\text{(future goal)}}{\text{(current customer satisfaction level)}}$$

Table 3.11. Results of competitor analysis and improvement ratio values.

Item number	**Our Product Today**	**Competitor 1 (Arçelik)**	**Competitor 2 (Veito)**	**Our Product Future)**	**Improvemet Ratio**
1	1	5	3	4	4
2	1	3	2	3	3
3	1	5	4	5	5
4	1	1	1	1	1
5	1	3	4	5	5
6	1	2	1	4	4
7	1	4	3	4	4
8	1	5	4	5	5
9	1	3	4	4	4
10	1	5	5	5	5
11	1	3	5	5	5
12	1	4	3	5	5
13	1	3	4	4	4
14	1	4	3	4	4
15	1	5	4	5	5
16	1	3	4	4	4
17	1	2	3	3	3
18	1	4	3	5	5

3.1.7. Step 7: Sales Point Calculation of Customer Requirements:

Sales points of all customer requirements are fed from the results of Kano Questionnaire. As mentioned before, companies show their successes in the QFD by sales point column. In proposed method, advantages and successes are gained by knowing the significance level of each customer expectations which can be evaluated by Kano questionnaire results. Therefore, the sales points of each customer are assigned according to Kano clusters. In order to find the sales points, the weights of the clusters multiplied by the corresponding Kano model indices which are assigned as 0, 0.5, 1 and 1.5 for indifference requirement, must-be requirement, one-dimensional requirement and attractive requirement, respectively and then sum up all. The Kano model index assignments are done according to articles in the literatures [2, 21, 22]. Example of sales point calculation according to Equation 2.17 and Equation 2.18 is done for customer expectation 1 at below. Others are listed in Table 3.13.

$$w_{\mathrm{j}} = \frac{f_{\mathrm{j}}}{f_{\mathrm{A}} + f_{\mathrm{O}} + f_{\mathrm{M}} + f_{\mathrm{I}}}$$
$$j = A, O, \ldots, I$$

where w_{j} represents the weight of Kano cluster j and f_j represent frequency of Kano cluster j. Also, f_{A}, f_{O}, f_{M}, and f_{I}, indicate the frequency of attractive attribute, one-dimensional attribute, must-be attribute and indifference attribute, respectively.

$$SP_{\mathrm{i}} = w_{\mathrm{A}} \times k_{\mathrm{A}} + w_{\mathrm{O}} \times k_{\mathrm{O}} + w_{\mathrm{M}} \times k_{\mathrm{M}} + w_{\mathrm{I}} \times k_{\mathrm{I}}$$
$$i = 1, 2, \ldots, n$$

where SP_i indicates sales point of customer expectation i. w_A,w_O,w_M and w_I shows weight of attractive attribute, one dimensional attribute, must-be attribute and indifference attribute, respectively. Similarly, k_A, k_O, k_M and k_I represents Kano model indices of attractive attribute, one dimensional attribute, must-be attribute and indifference attribute, respectively [23, 24].

Table 3.12. Values that are used for calculation of SP_1.

Frequency of attractive attribute	9
Frequency of one-dimensional attribute	0
Frequency of must-be attribute	1
Frequency of indifference attribute	45

$$w_{\mathrm{A}} = \frac{9}{55} = 0.16$$
$$w_{\mathrm{O}} = \frac{0}{55} = 0.00$$
$$w_{\mathrm{A}} = \frac{1}{55} = 0.02$$
$$w_{\mathrm{A}} = \frac{45}{55} = 0.82$$
$$SP_{\mathrm{i}} = (w_{\mathrm{A}})(k_{\mathrm{A}}) + (w_{\mathrm{O}})(k_{\mathrm{O}}) + (w_{\mathrm{M}})(k_{\mathrm{M}}) + (w_{\mathrm{I}})(k_{\mathrm{I}})$$
$$SP_1 = (0.16)(1.5) + (0)(1) + (0.02)(0.5) + (0.82)(0)$$

In this table, sales points which show the competitive advantage of the company are calculated. For example item 9 which is about easily cleanable design is classified as one-dimensional attribute and has one of the highest sales points. Most of the surveyee thought it as important design issue. Thus, if easily cleanable design is provided by the company, it provides to start one step ahead from other companies.

Table 3.13. Sales Point values of customer requirements.

Item number	**Kano Classification**	**Sales Point**
1	I	0.25
2	O	0.94
3	M	0.68
4	I	0.69
5	M	0.64
6	O	0.8
7	I	0.69
8	I	0.68
9	O	0.86
10	I	0.62
11	M	0.46
12	M	0.68
13	O	0.61
14	O	0.79
15	O	0.63
16	I	0.52
17	I	0.13
18	I	0.56

3.1.8. Step 8: Calculation of Absolute and Relative Weights of Customer Requirements

In this step, according to Equation 2.28 and Equation 2.29, absolute weight and relative weight of each customer requirement are calculated. The absolute weight and relative weight calculations of item 1 are written as an example at below.Also Table 3.15 shows all relative and absolute weight solutions of all customer needs.

Table 3.14. Values that are used for calculation of relative & absolute weight of item 1.

Kano classification	I (indifference requirement)
Adjustment factor	0.16
Rank of importance and importance value	H (high)(4)
Our product today	1
Competitor 1 (Arçelik)	5
Competitor 2 (Veito)	3
Our product future	4
Improvement ratio	4
Sales point	0.25
Maximum absolute weight of customer specifications	15.03

$$\text{Absolute Weight} = (m_i \times \text{importance} \times IR_i \times \text{sales point}_i) = (0.16 \times 4 \times 4 \times 0.25)$$
$$\text{Relative weight} = \frac{\text{absolute weight}_i}{(\text{maximum absolute weight})} = 0.65/15.03 = 0.04 \tag{3.1}$$

According to the absolute weight results, the most important customer expectation is item 12 which is about water dripping from the kettle body surface. Most people

Table 3.15. Absolute and relative weight results of customer expectations according to first model.

Item number	**Absolute Weight**	**Relative weight**
1	0.65	0.04
2	8.71	0.58
3	11.19	0.74
4	0.65	0.04
5	7.62	0.51
6	12.16	0.81
7	1.22	0.08
8	4.72	0.31
9	9.64	0.64
10	4.34	0.29
11	5.36	0.36
12	15.03	1
13	5.64	0.38
14	11.51	0.77
15	9.84	0.65
16	2.93	0.19
17	0.12	0.01
18	5.24	0.35

answer the Kano Questionnaire about this item as must be or one- dimensional, thus it becomes most important customer expectation. Therefore, all relative weight calculations are done according to this point, 15.03. And then, item 6 that is a desire about comfortable and ergonomic handle comes. On the other hand, handle dimensions, item 17, consider as least important customer expectation which is very questionable, because handle dimension is highly related with ergonomic design criteria.

3.1.9. Step 9: Determining Engineering Specifications

At the very beginning, the aim of this thesis is to convert the customer language to the engineering languages and thus understand the final users better. Up to this point, all we did was to find and list what the customer wants, to evaluate the achieving levels of competitors' performance, and to calculate the real weights of the customer needs in the product or service. In other words, all examinations are done according to customers' what lists. In this step, we will complete the missing point of the design stage; engineering specifications examinations.

In this point, we define the engineering criteria about the kettle, however we just concentrate on how we can design more ergonomic kettle. Thus, only ergonomic designs are determined. How list are explained in the following part and show in Table 3.16.

(i) Volume: Volume defines the water capacity of kettle. Generally, 2 or 1.7 liter is preferred by the customers.

(ii) Handle dimensions: Good handle design is important in all kinds of daily activities for products that are efficient, safe and attractive to buy. The contact between the hand and bulky and wide handle brings about awkward, inaccurate or unsafe conditions. The simple act of power gripping suggests the desirable thickness, length and a position of a handle. Therefore, the handle should be thick enough to separate the finger-tips from the palm and to prevent forming local high pressure at any point [53]. According to Patkin et. al. [53], the length of handle should be at least 10 to 15 cm to fit the width of the palm, longer for the large-handed populations. Also, the thickness of handle should be 3 to 4 cm, according to maximum power of an adult male. Thickness should be determined in order to allow the thumb to just cover the end of the index and middle fingers.

(iii) Clearance between the handle and surface: According to handle diameter and length, the local pressure on the palm may be prevented, whereas, the pressure on the fingers due to body surface may be eliminated by the adequate and sufficient gap between the body surface and handle. Adequate clearance avoids finger damage. Moreover, handle should have a space between handle edge and body surface of no less than 2.5 cm to prevent burning hand on side of kettle [58].

(iv) Shape: Here, shape consists of both body shape and handle shape. However, they should not be confused with the dimensions of them. The important points in this engineering specification are to define the location of connection point of the handle and body and to determine the geometrical structure of the body and handle. Conical or cylindrical shape of the body leads to change of center of gravity, and thus it affects the moment and force applying on the wrist while holding the kettle. The moment due to the weight of kettle and water balances with the moment and force on the wrist with respect to contact point of handle and hand. On the other hand, the shape of handle determines the posture of the wrist and the perpendicular distance from the center point.

(v) Lid shape and dimension: Lid diameter becomes significant while the water is being put into the kettle. Due to the small lids, holding the kettle under the spout becomes hard, because, in that case, some amount of water flows from the outer surface of the body. On the other hand, wide lids are also seen as unnecessary. Therefore, optimum dimensions, which are determined by anthropometric data of the customers where the kettle is tried to sell, should be defined at the beginning of the sketch period of product manufacturing.

(vi) Appearance of resistance: The location of the resistance is related with the restriction about the minimum amount of water putting into the kettle while heating some amount of water. Visible resistance brings about two problems. Firstly, cleaning the calcification on the resistance is really hard. Secondly, the heat is transferred to the water by convection thus if the resistance is not completely covered by the water, resistance transfers some of the heat to the air in the kettle. However, if water covers resistance completely, then al heat is used for heating the water. On the other hand, if kettle has hidden resistance, there is no more need to state any restriction about putting minimum amount of water that should be put in to the kettle while heating some amount of water.

(vii) Surface material: Easy cleanable feature is gained by selecting right materials for the surface. Also, thermal conductivity is another significant feature of the kettle. Glass and metal surfaces have high thermal conductivity thus they may lead to burning of finger, especially if the gap between the handle and surface is short, whereas plastic surfaces do not have high thermal conductivity.

(viii) Weight: It affects the moment and force on the wrist and the force that is applied by hand. Heavy kettle causes to hold kettle with awkward posture which forces the wrist and arm needlessly.

(ix) Handle material: Handle material is significant because, the material that covers the handle prevents the sliding. Little shape changes like thickened on the center of handle besides the types of materials eliminate the sliding risks. Also, sharp edges which may cause injury or local pressure can be eliminated by covering the handle with a material.

(x) Length of power cord: This feature is seen as important for some customers, thus it is listed as one of a how lists. During the customer survey, it was found that unnecessarily long cable bothers some of the users.

(xi) Base shape and dimensions: During the market survey, it was found out that, the circular base shape is most preferred ones. Circular shape provides to put the kettle on the base in any way.

(xii) Thermostat: A thermostat is a component of a control system which senses the temperature of a system. In the kettle, thermostat is used to shut down the kettle when the water becomes boiling temperature.

(xiii) Insulation material: Insulation material is used for covering the inside of kettle body. It is one of the most important design criteria of the kettle, because most users want to keep the heat inside the kettle after boiling. Heat loss should be minimal.

Table 3.16. List of engineering specifications.

Item number	**Engineering Specifications**
1	Volume
2	Handle dimensions
3	Clearance between handle and body
4	Shape
5	Lid shape and dimension
6	Appearance of resistance (hidden or not)
7	Surface material
8	Weight
9	Handle material
10	Length of power cord
11	Base shape and dimension
12	Thermostat
13	Insulation material

3.1.10. Step 10: Determining the Relationships between What Lists and How Lists

In this step, the relationships between the how lists and what lists is determined. This is the step where the customer language is translated to the engineering specification by debating the relationships of every customer expectations with every engineering specification. Here, the degrees of relationships which can be seen at Table 3.17are graded by the designer team.

3.1.11. Step 11: Calculations of Weights of Engineering Specifications

This step is the last step of the first proposed model which will give the importance rank of the engineering specifications while designing an ergonomic kettle. For the calculations, Equation 2.30 and Equation 2.31 are used. For getting the solutions of each engineering specification, each related relationship level is multiplied with relative weights of related customer expectations, and then they are added. The calculations of first specification, volume, are written below as an example.

For specification 1 (volume):

Volume has a strong relationship with the ergonomic and comfortable handle design due to its effect on the forces on hand-arm system (customer expectation 6). Moreover, it has medium relationship with expectation about good design for easy cleaning (customer expectation 9). Cleaning the inside of the kettle is hard if the volume is low. Furthermore, if the volume increases, then the weight of kettle also increases. Thus there is a strong relationship between volume and the weight of the kettle (customer expectation 16). Volume and expectation abou not dripping water from the surface (customer expectation 12) has medium relationship. There is a weak relationship with volume and not very big handle expectation (customer expectation 17).

Table 3.17. A relationship matrix of What Lists and How Lists.

Item number	**ES-1**	**ES-2**	**ES-3**	**ES-4**	**ES-5**	**ES-6**	**ES-7**	**ES-8**	**ES-9**	**ES-10**	**ES-11**	**ES-12**	**ES-13**
Item 1						S							
Item 2							S						S
Item 3												S	
Item 4												W	
Item 5				W									
Item 6	W	S	S	S				M	S				
Item 7				S						S	M		
Item 8				S							S		
Item 9	M	M	M	S	S	M	W	W	W	W	W		W
Item 10				S		S							
Item 11				W									
Item 12	M			S	S								
Item 13				S	S								
Item 14							S		S				S
Item 15		S	S	M									
Item 16	S	W						S	M				
Item 17	W	S	S	M				M					
Item 18		S	W					M	S				

Table 3.18. Values that are used for calculation of relative & absolute weight of engineering specification 1.

Relative weight of customer expectation 6	0.8
Relative weight of customer expectation 9	0.64
Relative weight of customer expectation 12	1.00
Relative weight of customer expectation 16	0.19
Relative weight of customer expectation 17	0.01
Maximum absolute weight of customer specifications	15.03

$$\text{absolute weight}_z = \sum_{i=1}^{n} \text{relative weight}_i \times \text{relationship}_{iz}$$

$$\text{Absolute weight of engineering specification}_1$$

$$= 9 \times 0.81 + 3 \times 0.64 + 3 \times 1$$

$$+ 9 \times 0.19 + 1 \times 0.01$$

$$\text{relative weight}_z = \frac{\text{absolute weight}_z}{max(\text{absolute weight})}$$

$$\text{Relative weight of engineering specification 1} = \frac{13.97}{34.43} = 0.41$$

Table 3.19 shows all relative and absolute weight results of each engineering specifications. According to the results the most important engineering criteria is shape of the kettle. And then, handle dimension and handle material come. The most insignificant specifications are listed as cable length, volume, and the base dimension, respectively

In Table 3.20, HOQ with all values and results are presented.

Table 3.19. The weight results of each engineering specification.

Item number	**Explaination**	**Absolute Weight**	**Reative weight**
1	Volume	13.97	0.41
2	Handle dimensions	18.5	0.54
3	Clearance between handle and body	15.51	0.45
4	Shape	34.43	1
5	Lid shape and dimension	18.15	0.53
6	Appearance of resistance	4.91	0.14
7	Surface material	12.75	0.37
8	Weight	10.03	0.29
9	Handle material	18.54	0.54
10	Length of cable	1.37	0.04
11	Base shape and dimension	3.71	0.11
12	Thermostat	6.74	0.2
13	Insulation material	12.75	0.37

Table 3.20. HOQ of first proposed model.

			ENGINEERING SPECIFICATION																						
CUSTOMER EXPECTATIONS	KANO CLASIFICATION	ADJUSTMENT FACTOR (m)	volume (capacity)	handle dimensions	clearance between handle and surface	shape	lid dimension	appearance of resistance	surface materials	weight	handle materials	length of cable	base shape and dimensions	thermostat	insulation material	IMPORTANCE	VALUE OF IMPORTANCE	OUR PRODUCT TODAY	COMPETITOR 1 (arçelik)	COMPETITOR 2 (veito)	OUR PRODUCT FUTURE	IMPROVEMENT RATIO	SALES POINT	ABSOLUTE WEIGHT	RELATIVE WEIGHT
Item 1	I	0.16						S								H	4	1	5	3	4	4	0.25	0.65	0.04
Item 2	O	0.77							S						S	H	4	1	3	2	3	3	0.94	8.71	0.58
Item 3	M	0.82												S		H	4	1	5	4	5	5	0.68	11.19	0.74
Item 4	I	0.47												W		L	2	1	1	1	1	1	0.69	0.65	0.04
Item 5	M	0.80				W										M	3	1	5	4	5	5	0.64	7.62	0.51
Item 6	O	0.76	S	S	S	S				M	S					VH	5	1	2	1	4	4	0.80	12.16	0.81
Item 7	I	0.44				S						S	M			VL	1	1	4	3	4	4	0.69	1.22	0.08
Item 8	I	0.46				S							S			M	3	1	5	4	5	5	0.68	4.72	0.31
Item 9	O	0.70	M	M	M	S	S	M	W	W	W	W	W		W	H	4	1	3	4	4	4	0.86	9.64	0.64
Item 10	I	0.47				S		S								M	3	1	5	5	5	5	0.62	4.34	0.29
Item 11	M	0.58				W										H	4	1	3	5	5	5	0.46	5.36	0.36
Item 12	M	0.89	M			S	S									VH	5	1	4	3	5	5	0.68	15.03	1.00
Item 13	O	0.77				S	S									M	3	1	3	4	4	4	0.61	5.64	0.38
Item 14	O	0.73							S		S				S	VH	5	1	4	3	4	4	0.79	11.51	0.77
Item 15	O	0.62		S	S	M										VH	5	1	5	4	5	5	0.63	9.84	0.65
Item 16	I	0.47	S	W						S	M					M	3	1	3	4	4	4	0.52	2.93	0.19
Item 17	I	0.15	W	S	S	M				M						L	2	1	4	3	3	3	0.13	0.12	0.01
Item 18	I	0.47		S	W					M	S					H	4	1	4	3	5	5	0.56	5.24	0.35
	ABSOLUTE WEIGHT		13.97	18.50	15.51	34.43	18.15	4.91	12.75	10.03	18.54	1.37	3.71	6.74	12.75										
	RELATIVE WEIGHT		0.41	0.54	0.45	1.00	0.53	0.14	0.37	0.29	0.54	0.04	0.11	0.20	0.37										

In this model, item 12, having a kettle where water should not drip from the surface, has the maximum weight of 15.03. Thus, every other rating is normalized by this value. This result is very logical if we want to manufacture an ergonomic kettle which does not bother the users because of water trickling. According to conclusions, second significant customer need is to have a comfortable handle which should not stress the wrist. This is another user friendly design criteria. Third customer expectation is to have a kettle which is manufactured with good quality materials. Third attribute which is to have a kettle that is shut down automatically after boiling becomes forth significant customer attribute. Fifth customer attribute is about ergonomic design of the product. Adequate gap between the handle and kettle surface should be left in order to prevent local pressure on the fingers which occurs due to narrow gap. Sixth one is again related with friendly user characteristics. Having easy cleanable design is the sixth customer expectations. Item 2 about preventing heat loss is another important parameters of kettle design. Eight customer expectation is having a kettle which has a warning signal to indicate the end of heating operation. Ninth one is about lid dimensions. Tenth is about water level indicator. Eleventh significant expectation is about handle material which should prevent sliding of hand over the handle by covering the handle surface. Item 8 which is to have a circular base for putting the kettle on it from all ways should have higher importance, because it provided really easiness for the users. This feature also provides both left and right hand usage. Appearance of resistance and kettle weight are not seen as very important feature which is again very questionable. Heavy weight leads to unnecessary stress on the hand and wrist. Having an additional section on the bottom part for hiding the kettle, feature about putting minimum amount of water into the kettle before heating operations and loudly warning feature are seen as insignificant customer expectations.

List of engineering expectations, on the other hand, are listed as follows: Determining the geometry of the kettle which affects both the location of center of gravity of kettle and the connection type of handle and surface is the most important parameter during the design stage of the kettle. Also handle shape is very significant owing to the effects on hand posture. Because shape parameter becomes the most significant, the other ratings were normalized using rating of that parameter. handle dimension is the second important engineering specifications. Although, customer expectation about handle dimension is listed at the end of what lists, the QFD shows that engineering parameters about the handle shape and dimensions are one of the most significant specifications. Actually, all about hand posture and comfort are related with handle dimension that includes both width and length of handle. Handle material is third important engineering specification. It is all about heat and electric conductivity and mechanical friction between palm and handle. Fourth important engineering expectation is lid shape and dimensions. Clearance between the handle and outer surface which affects finger comfort, becomes fifth. Narrow gap squeezes the fingers thus leads to undesired local pressure. Volume becomes sixth feature. Surface materials and insulation material becomes seventh and eighth in this model. Likewise the handle material, surface material is again related with thermal conductivity. Weight becomes ninth. Although, weight is not seen as very important, it directly affects the posture of wrist and force and moment on the wrist. Therefore, this result is very questionable. Customer expectation about kettle weight also takes place on the lasts in the customer expectation list, therefore I think that this feature is not comprehended by most of the users. Parameters about thermostat, resistance appearance, base shape, and cable length, respectively, become the most insignificant engineering specifications.

3.2. Proposed Model 2: Fuzzy Kano and Fuzzy QFD (FKFQFD)

The only difference between the first proposed model (MQFD) and second proposed model (FKFQFD) is to use fuzzy numbers instead of crisp numbers. Exactly same calculations are done in the second model, thus just the changing values will be emphasized in this part. Three fuzzy set members; one for Kano classification values, one for importance values, and one for relationship values are built. The results of first four steps (determination of customer expectations, preparation of Kano questionnaire, evaluation of Kano questionnaire results and calculation of SI, DI and adjustment factor) are using exactly same in the second model.

3.2.1. Step 1: Determination of Customer Expectations

First step is exactly same with first step in MKQFD. Market survey should be done in order to learn customer expectations. 18 customer requirements are selected from the market survey results. In order to remember them, Table 3.3 can be checked.

3.2.2. Step 2: Making Kano Questionnaire:

Second step is also exactly same with second step in MKQFD. According to What list being determined in the first step, Kano Questionnaire should be prepared. Totally 36 questions are prepared for 18 customer expectations. Also 5 other questions about the genders, weights, heights, ages and vacations of the subjects are asked for making statistical inferences. On Table 1.5, functional and dysfunctional questions for the eleventh item are shown as an example. The actual Kano questionnaire both in Turkish and English versions that consists of 41 questions can be seen in Appendix A.

3.2.3. Step 3: Evaluation of Kano Questionnaire

Third step is also exactly same with third step in KQFD. At this step, results of Kano questionnaire are evaluated in the Kano evaluation table. Table 3.7 shows the results of Kano Questionnaire.

3.2.4. Determining the Adjustment Factors for each Customer Requirements

Forth step is also exactly same with forth step in KQFD. Equations 2.22, 2.23and 2.24 are used for calculations. Table 3.9 shows adjustment factor of all customer expectations.

3.2.5. Step 5: Determining the Importance of Customer Requirements

In the fifth step, corresponding values of importance that are developed by fuzzy set members are changed. As explained in the proposed model chapter, triangular type of fuzzy function is used in the model. Triangular Membership Functions (TMFs) are used same as applications in the literature. Lower, upper and core values can be checked from Table 2.4. According to algorithm, new values are listed at Table 3.21.

3.2.6. Step 6: Analysis of Competitors and Setting Future Target

Ratings of the competitors' performance and our performance are used exactly the same manner in the proposed model. Therefore, future target and improvement ratio values are also same. In order to recal the values, Table 3.11 can be checked.

3.2.7. Step 7: Sales Point Calculation of Customer Requirements

For determining the sales point of each customer requirement, a new fuzzy set membership function is utilized. Equations 2.26 and 2.27 are used for the calculations, but this time all of them are done also for upper and lower bounds for Kano model indexes. Table 3.23 shows the corresponding fuzzy values of each what list. Example calculations are done for Customer Expectation 1.

Table 3.21. Importance of customer requirement and corresponding Fuzzy Set members.

Item Numbers	**Importance**	**Rate of Importance**		
		Lower bound	**core**	**Upper bound**
1	H	3	4	5
2	H	3	4	5
3	H	3	4	5
4	L	1	2	3
5	M	2	3	4
6	VH	4	5	5
7	VL	1	1	2
8	M	2	3	4
9	H	3	4	5
10	M	2	3	4
11	H	3	4	5
12	VH	4	5	5
13	M	2	3	4
14	VH	4	5	5
15	VH	4	5	5
16	M	2	3	4
17	L	1	2	3
18	H	3	4	5

Table 3.22. Example calculations fuzzy SP for item 1.

Frequency of attractive attribute	9
Frequency of one-dimensional attribute	0
Frequency of must-be attribute	1
Frequency of indifference attribute	45

$$
\begin{aligned}
w_{\mathrm{j}} &= \frac{f_j}{f_A + f_O + f_M + f_I} \\
w_{\mathrm{A}} &= \frac{9}{55} = 0.16 \\
w_{\mathrm{O}} &= \frac{0}{55} = 0.00 \\
w_{\mathrm{M}} &= \frac{1}{55} = 0.12 \\
w_{\mathrm{I}} &= \frac{45}{55} = 0.82 \\
SP_{\mathrm{i}} &= w_{\mathrm{A}} \times k_{\mathrm{A}} + w_{\mathrm{O}} \times k_{\mathrm{O}} + w_{\mathrm{M}} \times k_{\mathrm{M}} + w_{\mathrm{I}} \times k_{\mathrm{I}}
\end{aligned}
$$

$$
\begin{aligned}
\text{lower bound od } \mathrm{SP}_1 &= 0.16 \times 1.2 + 0.02 \times 0.2 + 0.82 \times 0 = 0.20 \\
\text{core bound od } \mathrm{SP}_1 &= 0.16 \times 1.5 + 0.02 \times 0.5 + 0.82 \times 0 = 0.25 \\
\text{upper bound od } \mathrm{SP}_1 &= 0.16 \times 1.8 + 0.02 \times 0.8 + 0.82 \times 0.3 = 0.55
\end{aligned}
$$

3.2.8. Step 8: Calculation of Absolute and Relative Weights of Customer Requirements

For the calculations of absolute and relative weights of each customer specification, it should be mentioned how scalar multiplication of triangular fuzzy numbers (TFN) and summation of two symmetrical TFN are done. According to [35], the calculations can be represented as follows:

Table 3.23. Sales Points of customer requirements according to proposed model.

Item Numbers	**Importance**	**Sales Points**		
		Lower bound	**core**	**Upper bound**
1	I	0.2	0.25	0.55
2	O	0.66	0.94	1.24
3	M	0.41	0.68	0.98
4	I	0.53	0.69	0.99
5	M	0.38	0.64	0.94
6	O	0.54	0.8	1.1
7	I	0.5	0.69	0.99
8	I	0.49	0.68	0.98
9	O	0.6	0.86	1.16
10	I	0.42	0.62	0.92
11	M	0.27	0.46	0.76
12	M	0.4	0.68	0.98
13	O	0.38	0.61	0.91
14	O	0.53	0.79	1.09
15	O	0.42	0.63	0.93
16	I	0.36	0.52	0.82
17	I	0.08	0.13	0.43
18	I	0.38	0.56	0.86

$$\lambda\,[\alpha_1;\alpha_2] = [\lambda \times \alpha_1; \lambda \times \alpha_2] \tag{3.2}$$

$$[\alpha_1;\alpha_2] \times [\beta_1;\beta_2] = [\alpha_1 \times \beta_1; \alpha_2 \times \beta_2] \tag{3.3}$$

where α is a constant value, α_1 and α_2 are lower and upper bound of first fuzzy membership, and β_1 and β_2 are lower and upper bound of second fuzzy membership. During the calculation of absolute weight of customer expectations, two fuzzy membership functions (for importance of customer expectations, and sales points) are used.

The absolute and relative weight calculations of first customer requirement are shown at below. Table 3.27 shows all relative and absolute weight results of each engineering specification.

Table 3.24. Example calculations of absolute & relative weights for item 1.

Kano classification	I (indifference requirement)
Adjustment factor	0.16
Rank of importance and importance value	H (high)(3;4;5)
Our product today	1
Competitor 1 (Arçelik)	5
Competitor 2 (Veito)	3
Our product future	4
Improvement ratio	4
Sales point	[0.20;0.25;0.55]
Maximum absolute weight of customer specifications	21.71

$$
\begin{aligned}
\text{Absolute Weight} &= (m_i \times \text{importance} \times IR_i \times \text{sales point}_i) \\
&= [0.16 \times 3 \times 4 \times 0.20; 0.16 \times 4 \times 4 \times 0.25; 0.16 \times 5 \times 4 \times 0.55] \\
&= [0.38; 0.65; 1.77] \\
\text{Relative weight} &= \frac{\text{absolute weight}_i}{max\text{absolute weight}} \\
&= \left[\frac{0.38}{21.71}; \frac{0.65}{21.71}; \frac{1.77}{21.71}\right] \\
&= [0.02; 0.03; 0.08]
\end{aligned}
$$

3.2.9. Step 9: Determining Engineering Specifications

The next step, determining the engineering specifications, is absolutely same with first model. Engineering specifications and the reason of why they were chosen was explained on part 3.1.9. Moreover, Table 3.16 showed all how lists of HOQ.

3.2.10. Step 10: Determining the Relationship between What Lists and How Lists

Last modification at the proposed model is to use another fuzzy set membership function to represent the relationship between the how lists and what lists refer to Table 2.3 for the fuzzy variables and corresponding fuzzy numbers.

3.2.11. Step 11: Calculations of Absolute and Relative Weights of Engineering Specifications

In that point, just the calculations of absolute and relative weight of each engineering specification are left. In order to see an example for calculations, the calculations of first specification, volume, are written below. Moreover, on the next table, the results of all absolute and relative weights of engineering specifications can be seen.

Table 3.25. Absolute and relative weight results of customer expectations according to proposed model II.

Item Numbers	Absolute Weights			Relative Weights		
	Lower bound	**core**	**Upper bound**	**Lower bound**	**core**	**Upper bound**
1	0.38	0.65	1.77	0.02	0.03	0.08
2	4.59	8.71	14.36	0.21	0.4	0.66
3	5.1	11.19	20.14	0.24	0.52	0.93
4	0.25	0.65	1.4	0.01	0.03	0.06
5	3.01	7.62	14.96	0.14	0.35	0.69
6	6.57	12.16	16.72	0.3	0.56	0.77
7	0.88	1.22	3.5	0.04	0.06	0.16
8	2.28	4.72	9.05	0.1	0.22	0.42
9	5.03	9.64	16.25	0.23	0.44	0.75
10	1.95	4.34	8.6	0.09	0.2	0.4
11	2.33	5.36	11.05	0.11	0.25	0.51
12	7.05	15.03	21.71	0.32	0.69	1
13	2.32	5.64	11.22	0.11	0.26	0.52
14	6.2	11.51	15.89	0.29	0.53	0.73
15	5.25	9.84	14.49	0.24	0.45	0.67
16	1.34	2.93	6.16	0.06	0.13	0.28
17	0.04	0.12	0.58	0	0.01	0.03
18	2.66	5.24	10.08	0.12	0.24	0.46

For specification 1 (volume): Volume has a strong relationship with the ergonomic and comfortable handle design to reduce stress and force on hand and arm system (customer expectation 6). Moreover, it has medium relationship with expectation about good design for easy cleaning (customer expectation 9). Cleaning the inside of the kettle is hard if the volume is low. Furthermore, if the volume increases, then the weight of kettle also increases. Thus there is a strong relationship between volume and the weight of the kettle (customer expectation 16). Volume and expectation abou not dripping water from the surface (customer expectation 12) has medium relationship. And lastly, if the volume is too low, there is no enough space to connect an ergonomic handle on the surface. Thus, there is a weak relationship with volume and not very big handle expectation (customer expectation 17).

Table 3.26. Example calculations of fuzzy absolute & fuzzy relative weights for engineering specification 1.

Relative weight of customer expectation 6	(0.30; 0.56; 0.77)
Relative weight of customer expectation 9	(0.23; 0.44; 0.75)
Relative weight of customer expectation 12	(0.32; 0.69; 1.00)
Relative weight of customer expectation 16	(0.06; 0.13; 0.28)
Relative weight of customer expectation 17	(0.00; 0.01; 0.03)
Maximum relative weight result of engineering specifications	4.98

If n customer requirements and m technical specification exist, then

3.2.12. Step 12: Defuzzification of Relative Weights of Engineering Specifications

The last step is the operation of defuzzification of both engineering specifications It is made in order to make more understandable and meaningful judgments. Like the first proposed model, a certain list of importance ranks of engineering specifications and customer expectations are evaluated. For these operations, a simple "defuzz" command of MATLAB is used. A simple example of defuzzy calculation of first engineering specification can be seen at below. Because only triangular membership functions are used in the proposed model, "trimf" command is used to form membership functions. Moreover, on the next Table 3.29, the results of all absolute and relative weights of engineering specifications can be seen.

$$
\begin{aligned}
\text{absolute weight}_z &= \sum_{i=1}^{n} \text{relative weight of customer atribute}_i \times \text{relationship}_{iz} \\
&= [0.39; 1.13; 2.29] \\
\text{relative weight}_z &= \frac{\text{absolute weight}_z}{max(\text{absolute weight})} \\
&= \left[\frac{0.39}{4.98}; \frac{1.13}{4.98}; \frac{2.29}{4.98}\right] \\
&= [0.08; 0.023; 0.46]
\end{aligned}
$$

For specification 1 (volume) (for manual solving):

$$
y = \text{triangle}(x; 0.08, 0.23, 0.46) = \begin{cases} 0 & x \leq 0.08 \\ \frac{x-0.08}{0.23-0.08} & 0.08 \leq x \leq 0.23 \\ \frac{0.46-x}{0.46-0.23} & 0.23 \leq x \leq 0.46 \\ 0 & 0.46 \leq x \end{cases}.
$$

$$
F^{-1}_{\text{COG}}(A) = \frac{\int \mu_{\text{A}}(x)x\text{d}x}{\int \mu_{\text{A}}(x)\text{d}x}.
$$

$$
F^{-1}_{\text{COG}}(A) = \frac{\int_{0.08}^{0.23} \frac{x-0.08}{0.23-0.08} x\text{d}x}{\int_{0.08}^{0.23} \frac{x-0.08}{0.23-0.08}\text{d}x} + \frac{\int_{0.23}^{0.46} \frac{0.46-x}{0.46-0.23} x\text{d}x}{\int_{0.23}^{0.46} \frac{0.46-x}{0.46-0.23}\text{d}x}
$$

$$
F^{-1}_{\text{COG}}(A) = 0.26
$$

In Table 3.30, the results of both proposed models can be seen.

Table 3.27. Absolute and relative weights of each engineering specification according to proposed model II.

Item Numbers	**Absolute Weights**			**Relative Weights**		
	Lower bound	**core**	**Upper bound**	**Lower bound**	**core**	**Upper bound**
1	0.39	1.13	2.29	0.08	0.23	0.46
2	0.47	1.26	2.57	0.09	0.25	0.52
3	0.4	1.09	2.17	0.08	0.22	0.44
4	0.79	2.29	4.98	0.16	0.46	1
5	0.4	1.12	2.27	0.08	0.22	0.46
6	0.13	0.41	1	0.03	0.08	0.2
7	0.3	0.83	1.69	0.06	0.17	0.34
8	0.16	0.6	1.47	0.03	0.12	0.29
9	0.44	1.22	2.46	0.09	0.25	0.5
10	0.02	0.13	0.46	0	0.03	0.09
11	0.08	0.29	0.83	0.02	0.06	0.17
12	0.14	0.42	0.95	0.03	0.08	0.19
13	0.3	0.83	1.69	0.06	0.17	0.34

Table 3.28. Deffuzification code in MATLAB for calculation of engineering specification 1.

Lower bound = 0.08
Core = 0.23
Upper bound = 0.46
$X1$ = 0:0.01:1
$MF1$ = trimf(X1,[0.01 0.06 0.18]),
DF1 = defuzz(X1,MF1,'centroid')
DF1 = 0.08

Table 3.29. Defuzzification results of each engineering specification.

Item Numbers	Absolute Weights			Relative Weights			Defuzzy Relative Weights
	Lower bound	**core**	**Upper bound**	**Lower bound**	**core**	**Upper bound**	
1	0.39	1.13	2.29	0.08	0.23	0.46	0.26
2	0.47	1.26	2.57	0.09	0.25	0.52	0.29
3	0.4	1.09	2.17	0.08	0.22	0.44	0.25
4	0.79	2.29	4.98	0.16	0.46	1	0.54
5	0.4	1.12	2.27	0.08	0.22	0.46	0.25
6	0.13	0.41	1	0.03	0.08	0.2	0.10
7	0.3	0.83	1.69	0.06	0.17	0.34	0.19
8	0.16	0.6	1.47	0.03	0.12	0.29	0.15
9	0.44	1.22	2.46	0.09	0.25	0.5	0.28
10	0.02	0.13	0.46	0	0.03	0.09	0.04
11	0.08	0.29	0.83	0.02	0.06	0.17	0.08
12	0.14	0.42	0.95	0.03	0.08	0.19	0.10
13	0.3	0.83	1.69	0.06	0.17	0.34	0.19

Table 3.30. Engineering specification weight results of both proposed models.

Item Numbers	Relative Weights of First Model	Relative Weights of Second Model			Defuzzy Relative Weights
		Lower bound	core	Upper bound	
1	0.41	0.08	0.23	0.46	0.26
2	0.54	0.09	0.25	0.52	0.29
3	0.45	0.08	0.22	0.44	0.25
4	1	0.16	0.46	1	0.54
5	0.53	0.08	0.22	0.46	0.25
6	0.14	0.03	0.08	0.2	0.1
7	0.37	0.06	0.17	0.34	0.19
8	0.29	0.03	0.12	0.29	0.15
9	0.54	0.09	0.25	0.5	0.28
10	0.04	0	0.03	0.09	0.04
11	0.11	0.02	0.06	0.17	0.08
12	0.2	0.03	0.08	0.19	0.1
13	0.37	0.06	0.17	0.34	0.19

When we look and compare the numbers, it seems that results of the first model are closer to the upper bounds of the second proped model's results whereas the deffuzification results are closer to core values. This can be explained by two reasons:

- Firstly, deffuzzification is done according to center of gravity deffucification technique. If one of the maxima methods is used, then differents results which are closer to upper bound can be found.
- Secondly, results of first model are calculating by dividing the absoute results with maximum absolute weight of engineering specifications, therefore, "1" is calculated for the most important one. However, deffuzification method cannot guarantee "1" for any of engineering specifications.

Table 3.31. HOQ of second proposed model.

CUSTOMER EXPECTATIONS	KANO CLASIFICATION	ADJUSTMENT FACTOR (m)	ENGINEERING SPECIFICATIONS: volume (capacity)	handle dimensions	gap between handle and surface	shape	lid dimension	appearance of resistance	surface materials	weight	handle materials	length of cable	base shape and dimensions	thermostat	insulation material
Item 1	I	0.16						S							
Item 2	O	0.77							S						S
Item 3	M	0.82												S	
Item 4	I	0.47												W	
Item 5	M	0.80				W									
Item 6	O	0.76	S	S	S	S				M	S				
Item 7	I	0.44				S						S	M		
Item 8	I	0.46				S							S		
Item 9	O	0.70	M	M	M	S	S	M	W	W	W	W	W		W
Item 10	I	0.47				S		S							
Item 11	M	0.58				W									
Item 12	M	0.89	M			S	S								
Item 13	O	0.77				S	S								
Item 14	O	0.73							S		S				S
Item 15	O	0.62		S	S	M									
Item 16	I	0.47	S	W						S	M				
Item 17	I	0.15	W	S	S	M				M					
Item 18	I	0.47		S	W					M	S				
ABSOLUTE WEIGHT	lower bound		0.39	0.47	0.40	0.79	0.40	0.13	0.30	0.16	0.44	0.02	0.08	0.14	0.30
	core		1.13	1.26	1.09	2.29	1.12	0.41	0.83	0.60	1.22	0.13	0.29	0.42	0.83
	upper bound		2.29	2.57	2.17	4.98	2.27	1.00	1.69	1.47	2.46	0.46	0.83	0.95	1.69
RELATIVE WIGHT	lower bound		0.08	0.09	0.08	0.16	0.08	0.03	0.06	0.03	0.09	0.00	0.02	0.03	0.06
	core		0.23	0.25	0.22	0.46	0.22	0.08	0.17	0.12	0.25	0.03	0.06	0.08	0.17
	upper bound		0.46	0.52	0.44	1.00	0.46	0.20	0.34	0.29	0.50	0.09	0.17	0.19	0.34
Defuzzification Relative Weight			0,26	0.29	0.25	0.54	0.25	0.10	0.19	0.15	0.28	0.04	0.08	0.10	0.19

CUSTOMER EXPECTATIONS	IMPORTANCE	VALUE OF IMPORTANCE: lower bound	Core	upper bound	OUR PRODUCT TODAY	COMPETITOR 1 (arçelik)	COMPETITOR 2 (veito)	OUR PRODUCT FUTURE	IMPROVEMENT RATIO	SALES POINT: lower bound	Core	upper bound	ABSOLUTE WEIGHT: lower bound	Core	upper bound	RELATIVE WEIGHT: lower bound	Core	upper bound
Item 1	H	3	4	5	1	5	4	4	4	0.20	0.25	0.55	0.38	0.65	1.77	0.02	0.03	0.08
Item 2	H	3	4	5	1	3	3	3	3	0.66	0.94	1.24	4.59	8.71	14.36	0.21	0.40	0.66
Item 3	H	3	4	5	1	5	5	5	5	0.41	0.68	0.98	5.10	11.19	20.14	0.24	0.52	0.93
Item 4	L	1	2	3	1	1	1	1	1	0.53	0.69	0.99	0.25	0.65	1.40	0.01	0.03	0.06
Item 5	M	2	3	4	1	3	5	5	5	0.38	0.64	0.94	3.01	7.62	14.96	0.14	0.35	0.69
Item 6	VH	4	5	5	1	2	4	4	4	0.54	0.80	1.10	6.57	12.16	16.72	0.30	0.56	0.77
Item 7	VL	1	1	2	1	4	4	4	4	0.50	0.69	0.99	0.88	1.22	3.50	0.04	0.06	0.16
Item 8	M	2	3	4	1	5	5	5	5	0.49	0.68	0.98	2.28	4.72	9.05	0.10	0.22	0.42
Item 9	H	3	4	5	1	3	4	4	4	0.60	0.86	1.16	5.03	9.64	16.25	0.23	0.44	0.75
Item 10	M	2	3	4	1	5	5	5	5	0.42	0.62	0.92	1.95	4.34	8.60	0.09	0.20	0.40
Item 11	H	3	4	5	1	3	5	5	5	0.27	0.46	0.76	2.33	5.36	11.05	0.11	0.25	0.51
Item 12	VH	4	5	5	1	4	5	5	5	0.40	0.68	0.98	7.05	15.03	21.71	0.32	0.69	1.00
Item 13	M	2	3	4	1	3	4	4	4	0.38	0.61	0.91	2.32	5.64	11.22	0.11	0.26	0.52
Item 14	VH	4	5	5	1	4	4	4	4	0.53	0.79	1.09	6.20	11.51	15.89	0.29	0.53	0.73
Item 15	VH	4	5	5	1	5	5	5	5	0.42	0.63	0.93	5.25	9.84	14.49	0.24	0.45	0.67
Item 16	M	2	3	4	1	3	4	4	4	0.36	0.52	0.82	1.34	2.93	6.16	0.06	0.13	0.28
Item 17	L	1	2	3	1	2	3	3	3	0.08	0.13	0.43	0.04	0.12	0.58	0.00	0.01	0.03
Item 18	H	3	4	5	1	4	5	5	5	0.38	0.56	0.86	2.66	5.24	10.08	0.12	0.24	0.46

4. RESULTS AND DISCUSSION

4.1. Comparison of First Model Results and Proposed Model Results

As explained in subsections 1.1 and 2.3.1, the major objective of this study is the determination of the importance rank of the engineering specification of a product during the design stage. Two similar models are proposed, in order to measure the reliability of the results which is done by comparing the results of both proposed models. Another important target is to proposed better models by integrating QFD, Kano and Fuzzy Logic when comparing with existing models. The only differences between the proposed models are got by using the fuzzy numbers instead of crisp numbers in the second model. Table 4.1 shows the absolute weights of the customer expectations derived both crisp approach and fuzzy approach.

Here the results are obtained by normalizing the values by dividing the individual rating with maximum one. In the first model, item 12, having a kettle where water should not drip from the surface, has the maximum weight of 15.03. Thus, every other rating is normalized by this value. This result is very logical if we want to manufacture an ergonomic kettle which does not bother the users because of water trickling. It is a well-known fact that kettle is preferred by most customers due to its practical usage, thus many of them seen this feature as one-dimensional or must be attribute. According to conclusions, second significant customer need is to have a comfortable handle which should not stress the wrist. This is another user friendly design criteria. Third customer expectation is to have a kettle which is manufactured with good quality materials. Quality of material is firstly about human health and then with cleaning issues. Poor quality material may react with water when being exposed to heat, and thus undesirable elements may get into the water. This is the worst scenario but it should always be under the control.

When it becomes to check the forth customer specification, it is seen that this is again about user friendly properties. Third attribute which is to have a kettle that is

Table 4.1. Relative weights of customer expectations generated by crisp approach and fuzzy approach.

Item Numbers	**Relative Weights of First Model**	**Relative Weights of Second Model**			**Defuzzy Relative Weights**
		Lower bound	**core**	**Upper bound**	
1	0.04	0.02	0.03	0.08	0.04
2	0.58	0.21	0.4	0.66	0.42
3	0.74	0.24	0.52	0.93	0.56
4	0.04	0.01	0.03	0.06	0.03
5	0.51	0.14	0.35	0.69	0.39
6	0.81	0.3	0.56	0.77	0.54
7	0.08	0.04	0.06	0.16	0.09
8	0.31	0.1	0.22	0.42	0.25
9	0.64	0.23	0.44	0.75	0.47
10	0.29	0.09	0.2	0.4	0.23
11	0.36	0.11	0.25	0.51	0.29
12	1	0.32	0.69	1.00	0.67
13	0.38	0.11	0.26	0.52	0.3
14	0.77	0.29	0.53	0.73	0.52
15	0.65	0.24	0.45	0.67	0.45
16	0.19	0.06	0.13	0.28	0.16
17	0.01	0	0.01	0.03	0.01
18	0.35	0.12	0.24	0.46	0.27

shut down automatically after boiling becomes forth significant customer attribute. It firstly prevents unnecessary energy consuming by lasting to work after boiling. Also it warns to users about finishing the heating operation. Fifth customer attribute is about ergonomic design of the product. Adequate gap between the handle and kettle surface should be left in order to prevent local pressure on the fingers which occurs due to narrow gap. Sixth one is again related with friendly user characteristics. Having easy cleanable design is the sixth customer expectations. Item 2 about preventing heat loss is another important parameters of kettle design. This parameter is all related with kettle surface material and insulation material inside it. Eight customer expectation is having a kettle which has a warning signal to indicate the end of heating operation. Ninth one is about lid dimensions. It is important because lid should have a dimension which does not hinder to clean inside of the kettle. Moreover, kettle lid should be opened easily not to force the people. Tenth is again about friendly user criteria which is about water level indicator. Eleventh significant expectation is about handle material which should prevent sliding of hand over the handle by covering the handle surface. Item 8 which is to have a circular base for putting the kettle on it from all ways should have higher importance, because it provided really easiness for the users. This feature also provides both left and right hand usage. The appearance of the resistance is not seen as very important. Actually it is very important because if it is related with the energy consuming feature. If a little amount of water is needed to heat and the kettle is not hidden, then much more water should be put into the kettle in order to cover the resistance with water, because when water does not cover the resistance, heat is needlessly transferred to the air. Kettle weight is not seen as very important feature which is again very questionable. Heavy weight leads to unnecessary stress on the hand and wrist. Having an additional section on the bottom part for hiding the kettle, feature about putting minimum amount of water into the kettle before heating operations and loudly warning feature are seen as insignificant customer expectations. Last customer attribute in the list is about handle dimension which is again very questionable, it is all about ergonomic design parameter. The rank can be seen in Table 4.2.

When the results of proposed model are analyzed, it is seen that the only changes are observed at the beginning part of the list. New results can be seen in the Table

Table 4.2. Rank of importance of customer expectations according to proposed model I.

Rank	**Item Number**	**Explainations**
1	item 12	While pouring the water, water should not trickle from the surface of body.
2	item 6	Handle of kettle should have a comfortable design which does not stress the hand and wrist.
3	item 14	The quality of the kettle materials should be good.
4	item 3	Kettle should be shut down automatically, after boiling.
5	item 15	The gap between the kettle body and handle should not discomfort the user fingers.
6	item 9	The kettle should be cleaned easily.
7	item 2	Heat loss should be minimal.
8	item 5	Kettle should have a indicator light which shows it is working.
9	item 13	The lid of kettle should be opened easily.
10	item 11	Kettle should have a water level indicator.
11	item 18	The handle of kettle can be covered by non-slippery material in order to prevent sliding and comfortable handling.
12	item 8	The base of the kettle should be circular in order to put the kettle on it from all ways.
13	item 10	Kettle has a hidden resistance for easy clean.
14	item 16	Kettle should have a light weight.
15	item 7	Kettle should have an additional division on the bottom part for hiding the cable.
16	item 1	Kettle should not have any restriction about putting minimum amount of water into the kettle before heating.
17	item 4	Kettle should have warning signal to indicate boiling.
18	item 17	The handle of kettle should not be very big.

4.3.

When we compare the results of two models it seems that similar results are gained, however interpretations make them different. Scoring the importance of the customer expectations or relationships of engineering specifications and customer attributes themselves are fuzzy, therefore calculating the results with fuzzy numbers instead of crisp values seems more sense.

Although second model is recommended, it does not give exact results like the first model in the first step. First choice for defuzzification method is to look maximum values either looking middle of maximum (MOM), or smallest of maximum (SOM), or largest of maximum (LOM). These choices give same results because of using only triangular membership functions. Also, they give exactly same results with the first model. Other choice is centroid defuzzification which returns the center of area under the fuzzy curve. This method is chosen because it returns the average importance level of each customer specification which seems more realistic. Some authors choose not to defuzzy the fuzzy results and get a group of fuzzy numbers. Therefore, some of them look upper boundaries for their own studies about whereas some of them make their interpretations according the core of fuzzy sets. However, these methods confuse the readers because of many valued conclusions. Thus, we also reject to use this kind of interpretations for our results and choose to make the defuzzifications.

During the Kano questionnaire evaluation, we see that some results are not same with what we expect. For example, Item 1 is classified as indifference attribute, however, it is very related with energy consuming thus we expect it as one dimensional or attractive attribute. Therefore, we ask the same Kano questionnaire to 5 people who have good mechanical engineering knowledge. As we expected, some results are changed. This shows us, if we make the Kano questionnaire after instructing the potential final users about the basic kettle working principles, we get different results. But, in that point it should not be forgotten that instructing the subjects about the topic should not be done by subjective interpretations of instructors. Because it leads to direct the subjects' thought to the instructors' opinions.

Table 4.3. Rank of importance of customer expectations according to proposed model II.

Rank	**Item Number**	**Explainations**
1	item 12	While pouring the water, water should not trickle from the surface of body.
2	item 3	Kettle should be shut down automatically, after boiling.
3	item 6	Handle of kettle should have a comfortable design which does not stress the hand and wrist.
4	item 9	The kettle should be cleaned easily.
5	item 14	The quality of the kettle materials should be good.
6	item 5	Kettle should have a indicator light which shows it is working.
7	item 15	The gap between the kettle body and handle should not discomfort the user fingers.
8	item 2	Heat loss should be minimal.
9	item 13	The lid of kettle should be opened easily.
10	item 11	Kettle should have a water level indicator.
11	item 18	The handle of kettle can be covered by non-slippery material in order to prevent sliding and comfortable handling.
12	item 8	The base of the kettle should be circular in order to put the kettle on it from all ways.
13	item 10	Kettle has a hidden resistance for easy clean.
14	item 16	Kettle should have a light weight.
15	item 7	Kettle should have an additional division on the bottom part for hiding the cable.
16	item 1	Kettle should not have any restriction about putting minimum amount of water into the kettle before heating.
17	item 4	Kettle should have warning signal to indicate boiling.
18	item 17	The handle of kettle should not be very big.

It is seen that there are small changes in the ranking lists when comparing conclusions of two models. Since we are mainly interested in the importance ranking of engineering specification, second model, which is more reliable is recommended for reaching main purpose. However, in order to compare the absolute and relative weights of engineering specifications, it is again continued to fill HOQ by both approaches. Table 4.4 shows the absolute weights of the engineering specifications derived both crisp approach and fuzzy approach.

Table 4.4 shows the final results of the HOQ. There are minor differences in the orders of both model results. Determining the geometry of the kettle which affects both the location of center of gravity of kettle and the connection type of handle and surface is the most important parameter during the design stage of the kettle. The location of center of gravity is important because it all affects the moment and stress on the wrist and forearm. Also handle shape is very significant owing to the effects on hand posture. Therefore, the result is very logical. Because shape parameter becomes the most significant, the other ratings were normalized using rating of that parameter, in both models.

According to both models, handle dimension is the second important engineering specifications. Although, customer expectation about handle dimension is listed at the end of what lists, the QFD shows that engineering parameters about the handle shape and dimensions are one of the most significant specifications. Actually, all about hand posture and comfort are related with handle dimension that includes both width and length of handle. Handle material is third important engineering specification. Material that covers the handle should both not conduct the heat and not be slippery. Therefore, choosing the right material becomes very important criteria for the users.

According to second model fourth important engineering specification is volume. This specification is related with most of the customer expectations such as comfortable handle design expectation or easy cleanable design expectation or kettle weight etc. Volume and weight has linear relationship. If one increases, then other increases or vice versa. However, according to first proposed model, fourth important engineering

Table 4.4. Relative weights of engineering specifications generated by crisp approach and fuzzy approach.

Item Numbers	**Explainations**	**Relative Weights of Model I**	**Relative Weights of Model II**			**Defuzzy Relative Weights**
			Lower bound	**core**	**Upper bound**	
1	Volume	0.41	0.08	0.23	0.46	0,26
2	Handle dimensions	0.54	0.09	0.25	0.52	0.29
3	Gap between handle and body	0.45	0.08	0.22	0.44	0.25
4	Shape	1	0.16	0.46	1	0.54
5	Lid shape and dimension	0.53	0.08	0.22	0.46	0.25
6	Appearance of resistance	0.14	0.03	0.08	0.2	0.1
7	Surface material	0.37	0.06	0.17	0.34	0.19
8	Weight	0.29	0.03	0.12	0.29	0.15
9	Handle material	0.54	0.09	0.25	0.5	0.28
10	Length of cable	0.04	0	0.03	0.09	0.04
11	Base shape and dimension	0.11	0.02	0.06	0.17	0.08
12	Thermostat	0.2	0.03	0.08	0.19	0.1
13	Insulation material	0.37	0.06	0.17	0.34	0.19

expectation is lid shape and dimensions. Fifth engineering specification is same in both proposed models. Clearance between the handle and outer surface which affects finger comfort, becomes fifth. Narrow gap squeezes the fingers thus leads to undesired local pressure. In the second model, sixth significant parameter is lid shape and dimension however, in the first model volume becomes sixth. Surface materials and insulation material becomes seventh and eighth in the first proposed model, whereas in the second model they are eighth and seventh, respectively. Likewise the handle material, surface material is again related with thermal conductivity. Most of time, burning accidents occur due to touching the kettle surface when it is hot. engineering specification about insulation material of kettle inside is also related with heat loss, thus it is also very significant. These are the only differences between the proposed models. Remain orders are same in both models. Weight becomes ninth. Although, weight is not seen as very important, it directly affects the posture of wrist and force and moment on the wrist. Therefore, this result is very questionable. Customer expectation about kettle weight also takes place on the lasts in the customer expectation list, therefore I think that this feature is not comprehended by most of the users. Parameters about thermostat, resistance appearance, base shape, and cable length, respectively, become the most insignificant engineering specifications. Table 4.5 and Table 4.6 show the rank of the importance of engineering specifications of proposed model I and proposed model II.

Second model give similar results with the first model. Thus, it can be seen that there are no difference between two models. But, actually, interpretation diversity makes them different. At the beginning of the first model, everything is accepted as a crisp, however customer interpretations about the product or service are originally fuzzy. No one makes their comments with either yes or no answers. Especially all choices in the Kano Questionnaire are fuzzy values thus representing the questionnaire results with fuzzy membership functions are seem more logical. Moreover, fuzzy evaluation process can reflect the uncertain issues inherent from common linguistic assessment. Also the proposed fuzzy-Kano and fuzzy-QFD model also provides flexibility that can adopt different linguistic certain levels by altering the index.

Table 4.5. Rank of importance of engineering specifications according to proposed model I.

Rank	**Item Numbers**	**Explaination**
1	item 4	Shape
2	item 2	Handle dimensions
3	item 9	Handle material
4	item 5	Lid shape and dimension
5	item 3	Gap between handle and body
6	item 1	Volume
7	item 7	Surface material
8	item 13	Insulation material
9	item 8	Weight
10	item 12	Thermostat
11	item 6	Appearance of resistance
12	item 11	Base shape and dimension
13	item 10	Length of cable

Table 4.6. Rank of importance of engineering specifications according to proposed odel II.

Rank	**Item Numbers**	**Explaination**
1	item 4	Shape
2	item 2	Handle dimensions
3	item 9	Handle material
4	item 1	Volume
5	item 3	Gap between handle and body
6	item 5	Lid shape and dimension
7	item 13	Insulation material
8	item 7	Surface material
9	item 8	Weight
9	item 8	Weight
10	item 12	Thermostat
11	item 6	Appearance of resistance
12	item 11	Base shape and dimension
13	item 10	Length of cable

4.2. Comparison of Proposed Model and Other Models in the Literature

This comparison is done especially for [18] which had used FL, QFD and Kano Model at the same time as our case. However, there are some basic differences between the two models.

- First of all, in [18], FLT was just used in the Kano Model, whereas in our study, Fuzzy Logic was integrated with both QFD and Kano Model.
- In our study, Kano Model indices (k) were represented by fuzzy membership functions. Upper and lower boundaries of the membership functions are 0 to 0.3, 0.2 to 0.8, 0.7 to 1.3 and 1.2 to 1.8 for indifference attributes, basic attributes, one-dimensional attributes and attractive attributes, respectively. However, in [18], k values were strictly assigned as 0.5, 1 and 2 for the basic attributes, one-dimensional attributes and attractive attributes, respectively. Here the most important difference is that indifference attribute was not covered by that study.
- Another difference occurs due to the assumption of Lee et al. about the importance level of the Kano clusters. It was assumed that the greatest impact on the product was determined in the following order: $M > O > A > I > R > Q$. But in our case, this kind of importance determination was not assigned. Even, we said that a competitive product or service should meet must-be attributes in order to respond customers' basic expectations, also should maximize the one-dimensional attributes for increasing customer satisfaction and should include as many attractive attributes as possible to provide differentiation when comparing with competitors. Therefore, assigning any importance level between the Kano clusters does not seem true, because each of them has different contribution in today's competitive markets.
- Another good property of our model is that according to satisfaction and dissatisfaction degrees, it can be understood which condition (product including or not including that attribute) has more influence on customers' purchase on product or service. It is measured by adjustment index (m).
- When comparing Kano Questionnaire evaluation, basic differences can be ob-

served between the two models. In our study, questionnaire response method only provides a single selection option. This means that, only one choice among “I like it that way”, “It must be that way.”, “I am neutral.”, “I can live with it that way.” or “I dislike it that way.” must be selected. However, in [18], weights were assigned to the choices for both functional and dysfunctional questions. And then, the clusters were assigned by cross products of the weights of choices. This kind of evaluation method may be applied in our case but in this type of calculations all answers cannot be taken into account during the sales point calculations. Therefore, this method is not suitable for our proposed model.

5. CONCLUSION

In this study, two proposed approaches, Modified Kano-Quality Function Deployment (MKQFD) and Fuzzy Kano – Fuzzy Quality Function Deployment (FKFQFD) are presented in order to design better product for the final users. They are proposed to improve the existing Kano – QFD approaches which accept the customer satisfaction as the key factor of the success in today's competitive world. In the literature, there exist several types of models integrating Kano Model and QFD. These integrated models improve the improvement ratio of QFD with some transformation function. The benefits gained through this integration can be summarized as follows:

(i) Kano model categorizes the customer expectations;however it cannot guide the design team about how they should use the information gained for the design of products.QFD, on the other hand, guides the designers by its House of Quality (HoQ) matrix which translates customer language to engineering language.

(ii) QFD assumes that there is a linear relationship between customer satisfaction level and product performance however Kano Model advocates that customer satisfaction changes lineraly or non-linearly depends on product attributes.

(iii) When QFD is used for product design, getting feedback only about well-known properties of the product is a shortcoming of QFD; However, with the help of Kano Model integration, the design team learns how customer react to innovative improvements in the products.

All in all, by integrating Kano Model and QFD approaches, how customer expectations are embedded to product attributes and which attribute comes first are both undestood; however, existing models still have some deficiencies about the applications The followings are main problems identified for existing Kano-QFD models:

(i) Orders of Kano Questionnaire and choices presented to customers are not random which may cause error due to bias.

(ii) Indifference attribute of the customers are not consideres in some of them due to the transformation functions.

(iii) Scoring of sales points are performed by marketting department itself.This rating may be biased and result in error.

To overcome these deficiencies, this study proposed an improved approach that is MKQFD. This new approach included tha following improvement steps.

(i) Kano Questions and choices are presented to customer in random orders. Randomzation is used in order to prevent error due to bias.
(ii) Indifference attribute is included in the model.
(iii) Scoring of the sales point were calculated based on formula based on results of Kano Questionnaire.

First proposed model (MKQFD) improved the traditional Kano-QFD models without considering Fuzzy Logic integration. The second model, FKFQFD, used same algorithm of the MKQFD by using fuzzy logic algorithm. FKFQFD uses fuzzy logic in the following steps:

(i) Canculation of importance of customer expectations.
(ii) Calculations of relationship between customer expectations and engineering specifications.
(iii) Representations of Kano clusters.

It is expected that the models developed through this study will improve the product design over the traditional Kano-QFD models. For this study, the steps of the proposed models were firstly explained, then the case study was performed . Case study about designing an ergonomic kettle desin was started with market survey. Firstly simple questions such as "What kinds of features do you expect from the kettle, what kinds of features did you get from your current kettle, what kinds of complaints do you have fom your current kettle?" were asked in order to find customer expectations and complaints. For the purpose of study, only ergonomic considerations about kettle design was taken into consideration. According to customer survey, 18 items were selected to determine what lists. Then Kano evaluation and competitor analysis were done finding the importance rank of customer expectations. After then, relationships between the customer expectations and engineering specifications were found. And lastly significance ranks of engineering specfications were calculated.

APPENDIX A: Kano Model Questionnaires Both in English and Turkish

A.1. Kano Model Questionnaire

By the help of this questionnaire, it is tried to learn which features are more significant for the current users and potential users. The results will be used for thesis studies by one of the master student from Bogazici University. The questions were established by Kano Model that is used for classification of the any product features. However, in order to get right result, the questions should be answered faithfully. The genders, weights, heights and ages of the subjects are important for making statistical inferences, thus please do not forget to fill annotated questions. Thank you for your participation.

Q1. If the gap between the handle and kettle surface is not wide and thus it discomforts you, how do you feel?

(i) I dislike it that way.
(ii) I can live it that way.
(iii) It must be that way.
(iv) I am neutral.
(v) I like it that way.

Q2. If kettle has a water level indicator, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q3. If the kettle shuts down itself automatically after boiling, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q4. If the kettle has a restriction about putting minimum amount of water before heating, how do you feel?

(i) It must be that way.
(ii) I am neutral.
(iii) I can live it that way.
(iv) I dislike it that way.
(v) I like it that way.

Q5. If the kettle lid is not opened easily, how do you feel?

(i) I dislike it that way.
(ii) I can live it that way.
(iii) It must be that way.
(iv) I am neutral.
(v) I like it that way.

Q6. If the kettle has a hidden resistance, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q7. If the kettle handle is covered by a material in order to prevent sliding, how do you feel?

(i) It must be that way.
(ii) I am neutral.
(iii) I can live it that way.
(iv) I dislike it that way.
(v) I like it that way.

Q8. If the kettle base is designed as a circular shape in order to put the kettle from any way, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q9. If the kettle has not a water level indicator, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q10. If the quality of kettle material is good, how do you feel?

(i) I dislike it that way.
(ii) I can live it that way.
(iii) It must be that way.
(iv) I am neutral.

(v) I like it that way.

Q11. If the kettle does not warn the customer loudly after boiling, how do you feel?

(i) I can live it that way.
(ii) I dislike it that way.
(iii) I am neutral.
(iv) I like that way.
(v) It must be that way.

Q12. If the kettle has an additional division part under the base for hiding the cable, how do you feel?

(i) It must be that way.
(ii) I am neutral.
(iii) I can live it that way.
(iv) I dislike it that way.
(v) I like it that way.

Q13. If the kettle weight is low, how do you feel?

(i) I dislike it that way.
(ii) I can live it that way.
(iii) It must be that way.
(iv) I am neutral.
(v) I like it that way.

Q14. If the kettle has an easy cleanable design, how do you feel?

(i) I dislike it that way.
(ii) I can live it that way.

(iii) It must be that way.
(iv) I am neutral.
(v) I like it that way.

Q15. If the kettle does not have a hidden resistance, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q16. If the kettle handle is large, how do you feel?

(i) I dislike it that way.
(ii) I can live it that way.
(iii) It must be that way.
(iv) I am neutral.
(v) I like it that way.

Q17. If the kettle keeps the heat inside the kettle in order to extend the cooling time, how do you feel?

(i) I can live it that way.
(ii) I dislike it that way.
(iii) I am neutral.
(iv) I like that way.
(v) It must be that way.

Q18. If the kettle does not have a warning light that shows it is working, how do you feel?

(i) I can live it that way.
(ii) I dislike it that way.
(iii) I am neutral.
(iv) I like that way.
(v) It must be that way.

Q19. If the kettle does not have a restriction about putting minimum amount of water before heating, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q20. If the quality of kettle material is not good, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q21. If the gap between the handle and kettle surface is not so close and thus, does not discomfort the user fingers, how do you feel?

(i) I dislike it that way.
(ii) I can live it that way.
(iii) It must be that way.
(iv) I am neutral.
(v) I like it that way.

Q22. If the kettle dribbles some amount of water from the surface, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q23. If the kettle does not have an additional division part under the base for hiding the cable, how do you feel?

(i) I can live it that way.
(ii) I dislike it that way.
(iii) I am neutral.
(iv) I like that way.
(v) It must be that way.

Q24. If the kettle does not have an easy cleanable design, how do you feel?

(i) I can live it that way.
(ii) I dislike it that way.
(iii) I am neutral.
(iv) I like that way.
(v) It must be that way.

Q25. If the kettle base is not designed as a circular shape in order to put the kettle from any way, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.

(iv) I can live it that way.
(v) I dislike it that way.

Q26. If the kettle does not keep the heat inside the kettle in order to extend the cooling time, how do you feel?

(i) I dislike it that way.
(ii) I can live it that way.
(iii) It must be that way.
(iv) I am neutral.
(v) I like it that way.

Q27. If the kettle handle is not very large, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q28. If the kettle handle is not covered by a material in order to prevent sliding, how do you feel?

(i) I can live it that way.
(ii) I dislike it that way.
(iii) I am neutral.
(iv) I like that way.
(v) It must be that way.

Q29. If the kettle weight is not low, how do you feel?

(i) I dislike it that way.

(ii) I can live it that way.
(iii) It must be that way.
(iv) I am neutral.
(v) I like it that way.

Q30. If the kettle handle does not have a comfortable and ergonomic design that does not force the wrist, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q31. If the kettle does not dribble some amount of water from the surface, how do you feel?

(i) It must be that way.
(ii) I am neutral.
(iii) I can live it that way.
(iv) I dislike it that way.
(v) I like it that way.

Q32. If the kettle warns the customer loudly after boiling, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q33. If the kettle has a warning light that shows it is working, how do you feel?

(i) I can live it that way.
(ii) I dislike it that way.
(iii) I am neutral.
(iv) I like that way.
(v) It must be that way.

Q34. If the kettle does not shut down itself automatically after boiling, how do you feel?

(i) I can live it that way.
(ii) I dislike it that way.
(iii) I am neutral.
(iv) I like that way.
(v) It must be that way.

Q35. If the kettle lid is opened easily, how do you feel?

(i) I dislike it that way.
(ii) I can live it that way.
(iii) It must be that way.
(iv) I am neutral.
(v) I like it that way.

Q36. If the kettle handle has a comfortable and ergonomic design that does not force the wrist, how do you feel?

(i) I like it that way.
(ii) It must be that way.
(iii) I am neutral.
(iv) I can live it that way.
(v) I dislike it that way.

Q37. What is your vocation?

Q38. How is your age?

Q39. How is your height?

Q40. How is your weight?

Q31. What is your gender?

(i) male
(ii) female

A.2. Kano Model Anketi

Bu anket araştırması ile kettle kullanan müşterilerin ve müşteri potansiyeli olan kişilerin kettle satın alırken nelere dikkat ettiğini belirlemeye çalışıyoruz. Elde edilecek bilgiler Boğaziçi Üniversitesi Endüstri Mühendisliği bölümünde yüksek lisans yapan bir öğrencinin tez çalışması olarak kullanılacaktır. Yapacağınız anketin soruları ürün özelliklerini sınıflandırmak için kullanılan Kano Model'inin yöntemlerine göre hazırlanmıştır. Ancak çalışmanın başarısı için soruların doğrulukla ve içtenlikle doldurulması gerekmektedir. Soruyu yanıtlayan kişinin bay veya bayan oluşu, genç veya yaşlı oluşu ve kilosu istatistiksel çıkarımlar açısından önemli olduğu için lütfen açıklama niteliğindeki soruları da doğru bir şekilde doldurunuz. İlgi ve katkılarınız için teşekkür ederiz.

S1. Kettle'ınızın gövdesi u boşluk dar olup kettle'ı tuttuğunuz zaman parmaklarınızı rahatsız ederse ne düşünürsünüz?

(i) Hiç hoşuma gitmez.
(ii) Hoşlanmam ama tahammül edebilirim.
(iii) Öyle olmasını beklerim.

(iv) Fark etmez.
(v) Çok hoşuma gider.

S2. Kettle'ınızda su seviye göstergesi olursa ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S3. Kettle'nızdaki su kaynadıktan sonra kettle'nız otomatik otomatik olarak kapanırsa ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S4. Kettle'da su kaynatabilmek için kettle'a konulması gereken minimum su miktarının olması size ne hissettirir?

(i) Öyle olmasını beklerim.
(ii) Fark etmez.
(iii) Hoşlanmam ama tahammül edebilirim.
(iv) Hiç hoşuma gitmez.
(v) Çok hoşuma gider.

S5. Kettle'ınızın kapağı kolay açılamıyorsa nasıl hissedersiniz?

(i) Hiç hoşuma gitmez.

(ii) Hoşlanmam ama tahammül edebilirim.
(iii) Öyle olmasını beklerim.
(iv) Fark etmez.
(v) Çok hoşuma gider.

S6. Kettle'ınızın su haznesinin tabanı düz ise (gizli rezistansa sahipsa) ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S7. Kettle'ınızın sapı kaymayı önleyici bir malzeme ile kaplıysa ne düşünürsünüz?

(i) Öyle olmasını beklerim.
(ii) Fark etmez.
(iii) Hoşlanmam ama tahammül edebilirim.
(iv) Hiç hoşuma gitmez.
(v) Çok hoşuma gider.

S8. Kettle'ı istediğiniz yönden tabana oturtabilmeniz için kettle'ın tabanı dairesel şekilde tasarlanırsa ne hissedersiniz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S9. Kettle'nızın su seviye göstergesi olması size ne düşündürür?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S10. Ketlle'ınızın malzeme kalitesi iyi ise ne düşünürsünüz?

(i) Hiç hoşuma gitmez.
(ii) Hoşlanmam ama tahammül edebilirim.
(iii) Öyle olmasını beklerim.
(iv) Fark etmez.
(v) Çok hoşuma gider.

S11. Kettle'nızdaki su kaynadıktan sonra kettle'ınız yüksek sesle uyarı vermezse ne düşünürsünüz?

(i) Hoşlanmam ama tahammül edebilirim.
(ii) Hiç hoşuma gitmez.
(iii) Fark etmez.
(iv) Çok hoşuma gider.
(v) Öyle olmasını beklerim.

S12. Kettle'nızın alt parçasında kablonun saklanabileceği ek bir bölme olması size ne düşündürür?

(i) Öyle olmasını beklerim.
(ii) Fark etmez.
(iii) Hoşlanmam ama tahammül edebilirim.
(iv) Hiç hoşuma gitmez.
(v) Çok hoşuma gider.

S13. Kettle'ınız hafifse ne hissedersiniz?

(i) Hiç hoşuma gitmez.
(ii) Hoşlanmam ama tahammül edebilirim.
(iii) Öyle olmasını beklerim.
(iv) Fark etmez.
(v) Çok hoşuma gider.

S14. Kettle'ınız kolay temizlenebilir bir tasarıma sahipse ne düşünürsünüz?

(i) Hiç hoşuma gitmez.
(ii) Hoşlanmam ama tahammül edebilirim.
(iii) Öyle olmasını beklerim.
(iv) Fark etmez.
(v) Çok hoşuma gider.

S15. Kettle'ınızın su haznesinin tabanı düz değil ise (gizli rezistansı yoksa) ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S16. Kettle'ınızın sapı büyükse ne düşünürsünüz?

(i) Hiç hoşuma gitmez.
(ii) Hoşlanmam ama tahammül edebilirim.
(iii) Öyle olmasını beklerim.
(iv) Fark etmez.
(v) Çok hoşuma gider.

S17. Kettle'ınız ısıyı içinde tutabiliyorsa ve böylelikle suyun soğuma süresini uzatabiliyorsa ne düşünürsünüz?

(i) Hoşlanmam ama tahammül edebilirim.
(ii) Hiç hoşuma gitmez.
(iii) Fark etmez.
(iv) Çok hoşuma gider.
(v) Öyle olmasını beklerim.

S18. Kettle'ınızın üzerinde çalıştığını gösteren bir uyarı ışığı bulunmuyorsa ne düşünürsünüz?

(i) Hoşlanmam ama tahammül edebilirim.
(ii) Hiç hoşuma gitmez.
(iii) Fark etmez.
(iv) Çok hoşuma gider.
(v) Öyle olmasını beklerim.

S19. Kettle'da su ısıtabilmek için kettle'a konulması zorunlu belli bir miktar suyun olmaması size ne düşündürür?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S20. Kettle'ınızın malzeme kalitesi iyi değilse ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.

(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S21. Kettle'ınızın gövdesi ve sapı arasındaki boşluk geniş olup kettle'ı tuttuğunuz zaman parmaklarınızı rahatsız etmiyorsa ne düşünürsünüz?

(i) Hiç hoşuma gitmez.
(ii) Hoşlanmam ama tahammül edebilirim.
(iii) Öyle olmasını beklerim.
(iv) Fark etmez.
(v) Çok hoşuma gider.

S22. Kettle'ınız suyu boşaltırken altından su damlatırsa ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S23. Kettle'ın alt parçasında kablonun saklanabileceği ek bir bölme olmaması size ne düşündürür?

(i) Hoşlanmam ama tahammül edebilirim.
(ii) Hiç hoşuma gitmez.
(iii) Fark etmez.
(iv) Çok hoşuma gider.
(v) Öyle olmasını beklerim.

S24. Kettle'nız kolay temizlenebilir bir tasarıma sahip değilse ne düşünürsünüz?

(i) Hoşlanmam ama tahammül edebilirim.

(ii) Hiç hoşuma gitmez.
(iii) Fark etmez.
(iv) Çok hoşuma gider.
(v) Öyle olmasını beklerim.

S25. Kettle'nızı, tabanına her yönden yerleştiremiyorsanız (tabanı dairesel şekilde değilse) ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S26. Kettle'ınız ısıyı içinde tutamıyorsa ve dışarıya ısı iletiyorsa ne düşünürsünüz?

(i) Hiç hoşuma gitmez.
(ii) Hoşlanmam ama tahammül edebilirim.
(iii) Öyle olmasını beklerim.
(iv) Fark etmez.
(v) Çok hoşuma gider.

S27. Kettle'ınızın sap boyutu büyük değilse ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S28. Kettle'ınızın sapı kaymayı önleyici bir malzeme ile kaplı değilse ne düşünürsünüz?

(i) Hoşlanmam ama tahammül edebilirim.
(ii) Hiç hoşuma gitmez.
(iii) Fark etmez.
(iv) Çok hoşuma gider.
(v) Öyle olmasını beklerim.

S29. Kettle'ınız hafif değilse ne düşünürsünüz?

(i) Hiç hoşuma gitmez.
(ii) Hoşlanmam ama tahammül edebilirim.
(iii) Öyle olmasını beklerim.
(iv) Fark etmez.
(v) Çok hoşuma gider.

S30. Kettle'ınızın bileği zorlayan, rahat olmayan bir sapı olursa ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S31. Kettle'ınız suyu boşaltırken altından su damlatmazsa ne düşünürsünüz?

(i) Öyle olmasını beklerim.
(ii) Fark etmez.
(iii) Hoşlanmam ama tahammül edebilirim.
(iv) Hiç hoşuma gitmez.
(v) Çok hoşuma gider.

S32. Kettle'ınız içindeki su kaynadıktan sonra yüksek sesle uyarı verirse ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S33. Kettle'nızın üzerinde çalıştığını belirten bir uyarı ışığı olursa ne düşünürsünüz?

(i) Hoşlanmam ama tahammül edebilirim.
(ii) Hiç hoşuma gitmez.
(iii) Fark etmez.
(iv) Çok hoşuma gider.
(v) Öyle olmasını beklerim.

S34. Kettle'nızdaki su kaynadıktan sonra kettle'nız otomatik olarak kapanmıyorsa ve kettle'ı elinizle kapatmak zorunda kalıyorsanız ne düşünürsünüz?

(i) Hoşlanmam ama tahammül edebilirim.
(ii) Hiç hoşuma gitmez.
(iii) Fark etmez.
(iv) Çok hoşuma gider.
(v) Öyle olmasını beklerim.

S35. Kettle'ınızın kapağı kalay açılabiliyorsa ne düşünürsünüz?

(i) Hiç hoşuma gitmez.
(ii) Hoşlanmam ama tahammül edebilirim.
(iii) Öyle olmasını beklerim.
(iv) Fark etmez.
(v) Çok hoşuma gider.

S36. Kettle'nızın bileği zorlamayan, ergonomik ve rahat bir sapı varsa ne düşünürsünüz?

(i) Çok hoşuma gider.
(ii) Öyle olmasını beklerim.
(iii) Fark etmez.
(iv) Hoşlanmam ama tahammül edebilirim.
(v) Hiç hoşuma gitmez.

S37. Mesleğiniz?

S38. Yaşınız?

S39. Boyunuz?

S40. Kilonuz?

S41. Cinsiyetiniz?

(i) bay
(ii) bayan

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