Product Development through Fuzzy and Crisp Based QFD Modelling – A Case Study

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Abstract: This paper employs Quality Function Deployment (QFD) methodology to translate customer needs and requirements into the quality characteristics to improve quality for an existing product or to develop a new product. QFD can bring out the product with improved quality, better performance, economic price, good aesthetic, and very important thing-accepted by customer because of fulfillment of their requirements & demands. QFD can correlate the customer requirements with the technical requirements of the company and then the target value can be fixed to improve the different characteristics that required by the customers. The study consists of two approaches to improve the design of domestic refrigerator using quality function deployment technique. The first one is the crisp approach. In this approach, traditional QFD technique was employed to build a quality plan for a domestic refrigerator. In the second stage of this study, fuzzy approach was used. Fuzzy set theory is integrated into house of quality (HOQ) to overcome the shortcomings of the traditional QFD and to capture the inherent impreciseness and vagueness of customer requirements and facilitate to prioritize QFD information. Improving high priority design requirements will ultimately increase customer satisfaction. At the final stage of the study, these two approaches have been compared with each other.

Keywords– Quality Function Deployment (QFD) Methodology, House of Quality (HOQ), Fuzzy QFD Approach, Triangular Fuzzy Number (TFN), Design Improvement, Case Study, Domestic Refrigerator.

1. INTRODUCTION

It is a common notion that competition in industries is becoming increasingly intense. Given the trend of business globalization, companies face challenges from both national and international competitors. To counter this threat, many of them focus on searching for sustainable advantages. The survival of a company is heavily dependent on its capacity to identify new customer requirements and to develop a new product [1]. Yoji Akao introduced the concept of QFD in Japan in 1966. According to Akao QFD is a method for developing a design quality aimed at satisfying the consumer and then translating the consumer's demand into design targets and major quality assurance points to be used throughout the production phase (Dean Edwin). QFD has been used as an important part of the product development process. QFD is an investment in people and information. It uses a cross functional team to determine customer requirements. QFD is a systematic and analytical technique for meeting customer expectation. QFD is a planning process for translating customer requirements (voice of the customer) into the appropriate technical requirements for each stage of product development and production (i.e. marketing, strategies, planning, product design and engineering, prototype evaluation, production process development, production, sales) [2] and [3]. The QFD concept is broken down into the two main activities: Product quality deployment and deployment of the quality function. Product quality deployment translates the "voice of the customer" into product control characteristics. Whereby, deployment of the quality function activities needed to assure that customer required quality is achieved. Deployment of the quality function examines the company response to the customer voice through an organized team approach [4]. To overcome difficulties related with QFD application, artificial intelligence techniques such as fuzzy logic is proposed to resolve some of QFD's drawbacks. To quantify the linguistic variables used in QFD, the fuzzy set theory is an excellent tool to help a design team to select proper alternatives in an uncertainty environment. Fuzzy logic permits consideration of the different meanings that may be given to the same linguistic expression [5]. Thus, the major contribution of the fuzzy set theory is its ability to represent vague data [6]. In this study two approaches (Crisp QFD and Fuzzy QFD) were used.

2. QFD METHODOLOGY

The most-used QFD methodology is the conventional manufacturing-based QFD, which is deployed through a four-phased sequence.

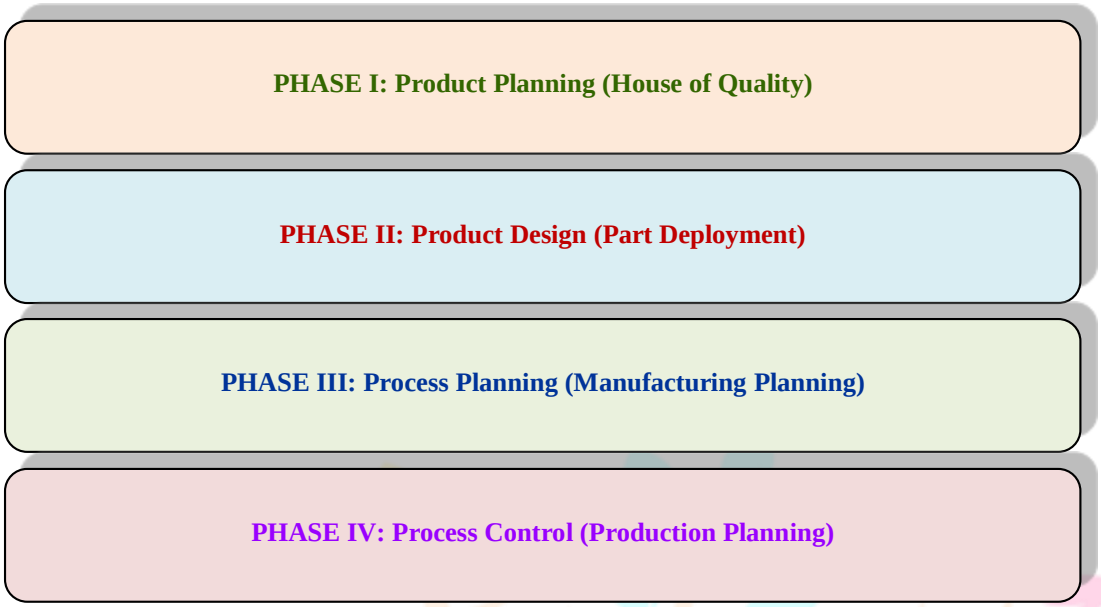

FIG. 1: The 4 Phases of QFD

PHASE I: Product Planning (House of Quality)
This phase is also known as the House of Quality. Building the House of Quality is generally led by the marketing department. Many organizations only get through this phase of a QFD process. Getting good data from the customer in Phase 1 is critical to the success of the entire QFD process. This information is usually gathered through conversations with the customer in which they are encouraged to describe their needs and problems. The list of requirements gathered in such an exercise must be structured before its entry in to the HOQ. The construction of Affinity and Tree Diagrams can be used to do this.

PHASE II: Product Design (Part Deployment)
This phase is led by the design engineering department. Product design requires creative and innovative team ideas. Product concepts are created during this phase and part specifications are documented. Parts that are determined to be most important to meeting customer needs are then deployed into process planning, or Phase 3.

PHASE III: Process Planning (Manufacturing Planning)
Process planning comes next and is led by manufacturing engineering. During process planning, manufacturing processes are flowcharted and process parameters (or target values) are documented.

PHASE IV: Process Control (Production Planning)
And finally, in production planning, performance indicators are created to monitor the production process, maintenance schedules, and skills training for operators. Also, in this phase decisions are made as to which process poses the most risk and controls are put in place to prevent failures. The quality assurance department in concert with manufacturing leads Phase 4.

3. FIRST APPROACH: TRADITIONAL QUALITY FUNCTION DEPLOYMENT

QFD is also known as the house of the quality (HOQ). QFD uses a matrix format to capture a number of issues pertinent and vital to the planning process. The QFD matrix consists of six parts.

The first part starts with constructing a list of product demands as voiced by the customer. The second part of the house of the quality is customers' competitive evaluations. The third part is to determine the quality characteristics. These quality characteristics, which are measurable, controllable that will impact on one or more customer demands. The fourth part is the correlation matrix to identify the interrelationship of each quality characteristic. The fifth part is an evaluation of the strength of the relationship between the customer demand and the technical requirements. The last part is the technical assessment. The output of the house of quality is not a product design but merely the requirements of the end product [7].

Figure 2 denotes the principal components of the horizontal and vertical portions of the matrix [8].

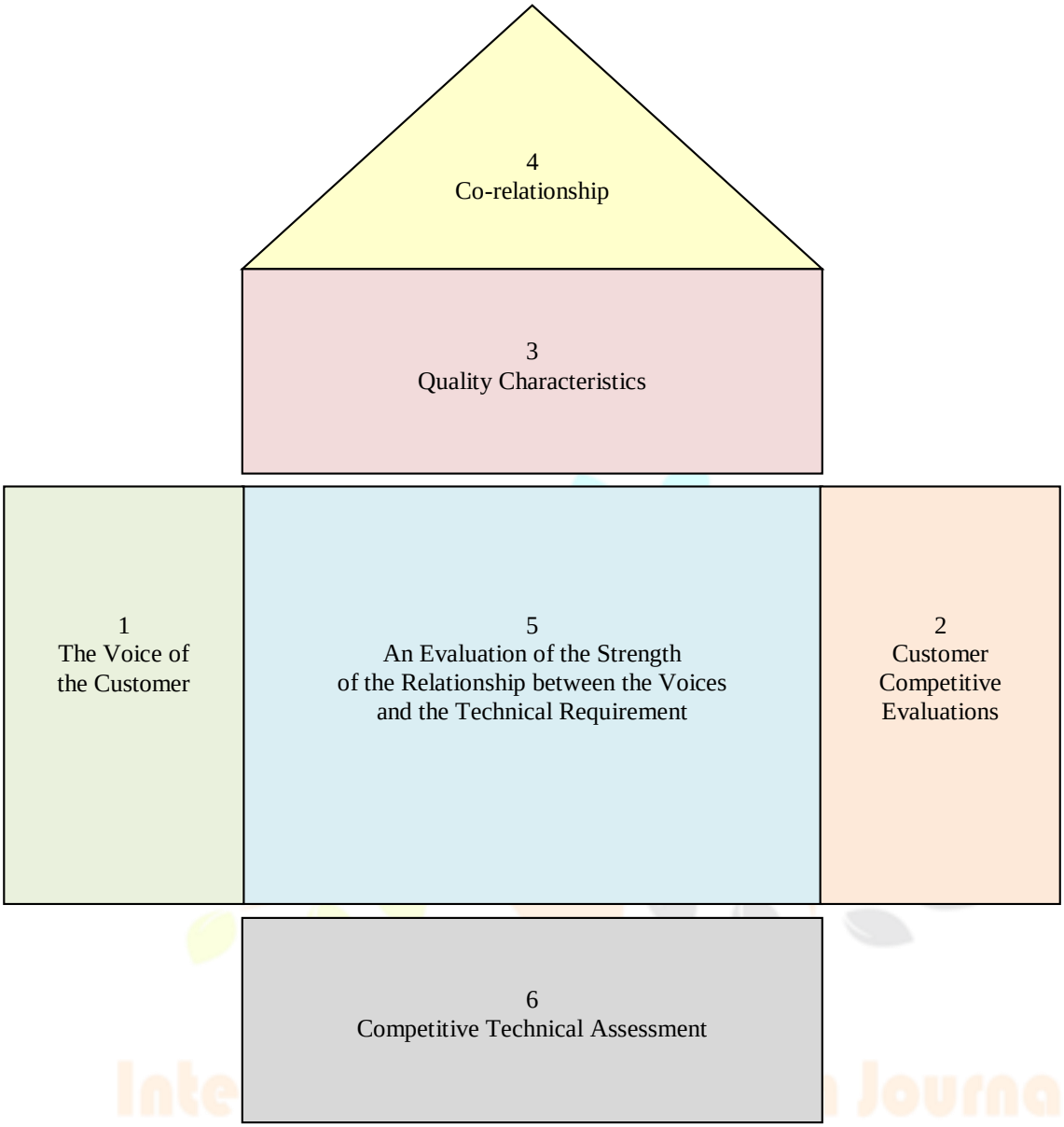

Fig. 2: The House of Quality

Stage 1: Determine the Customer Demands:

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

Stage 2: Customer competitive evaluations

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

Stage 3: Determine the Technical Requirements

In this stage, determined customer demands were translated into technical requirements. The objective is to translate each customer voice into one or more technical requirements. Each technical requirement should be measurable and global in nature and should satisfy the voice of the customer [9]. Customer requirements are expressed in customer language. In order to make them suitable for product design and product development, it is necessary to translate these requirements into technical requirements. Stage 2 has addressed the "what" question by identifying customers' requirements. This third stage addresses the "how" question by identifying the measurable and definable design features of the consumer product.

Stage 4: Interrelationship between technical requirements

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

Stage 5: Relationship matrix between hows and whats

After establishing the whats and hows, construction of house of quality continues with establishing the relationships between the customer voices and the technical requirements [10]. A customer requirement can relate to several design parameters, and a design parameter can relate to more customer requirements than one. QFD therefore uses the format of a matrix, in which all interactions between customer requirements and design parameters can be identified. To build the relationship matrix between hows and whats, it is necessary to establish if relationship exist between every what and every how. All relationships are categorized such as either strong, medium, or weak. A score of 9 is used to indicate a strong relationship between whats and hows. A score of 3 signifies a moderate relationship and 1 signifies a weak relationship between them.

Stage 6: Column Absolute Weights

Column Absolute Weights were calculated for each technical requirement that represent a combination of both the customers' level of importance and the strength of the relationships. Each demanded quality weight is multiplied by the relationship value in cells in its row. The products in each column are summed to give a Column Absolute Weight.

4. THE SECOND APPROACH: THE FUZZY QUALITY FUNCTION DEPLOYMENT APPROACH

HOQ in QFD can only state linguistic and vague ideas expressed by customers and the QFD technical team. Owning to vagueness frequently represented in decision data, the crisp values are inadequate to model real life situations. Considering the typical vagueness or imprecision of functional relationships between customer demands and technical requirements, it is difficult to identify them [11]. To solve the uncertainty or imprecision in QFD, numerous researchers have attempted to apply fuzzy set theory to QFD and have developed various fuzzy QFD approaches [12]. The use of fuzzy numbers becomes very important in decision making problems, where linguistic scales are adopted and where a panel of decision makers is involved in the judgment processes. Fuzzy logic allows taking into account a different meaning that may be given to the same linguistic expression. As a matter of fact, this is why the fuzzy approach has been so widely adopted in different research fields, as witnessed by the massive literature on the subject [13].

In FQFD approach, crisp values are translated into fuzzy numbers, which can be considered as probability distribution [14] used to test the significance of the coefficients. Mathematically,

$$A_{ij} = [\alpha_{1ij}, \alpha_{2ij}] \quad \text{(i)}$$

Where A_{ij} is a symmetrical triangular fuzzy number (TFN) which is defined by the interval $[\alpha_{1ij}, \alpha_{2ij}]$.

The TFN can be denoted as a triplet (a, b, c), where, a < = b < = c. When a=b=c, it is a non-fuzzy number by convention. A membership function can be defined as [15]:

$\mu_N(x)$ = 1, x=b
= (x-a) / (b-a), x v [a,b]
= (c-x) / (c-b), x v [b,c]
= 0, otherwise

5. CASE STUDY

A case study has been carried out for product development Domestic Refrigerator (Direct Cool type) with the help of QFD tool.

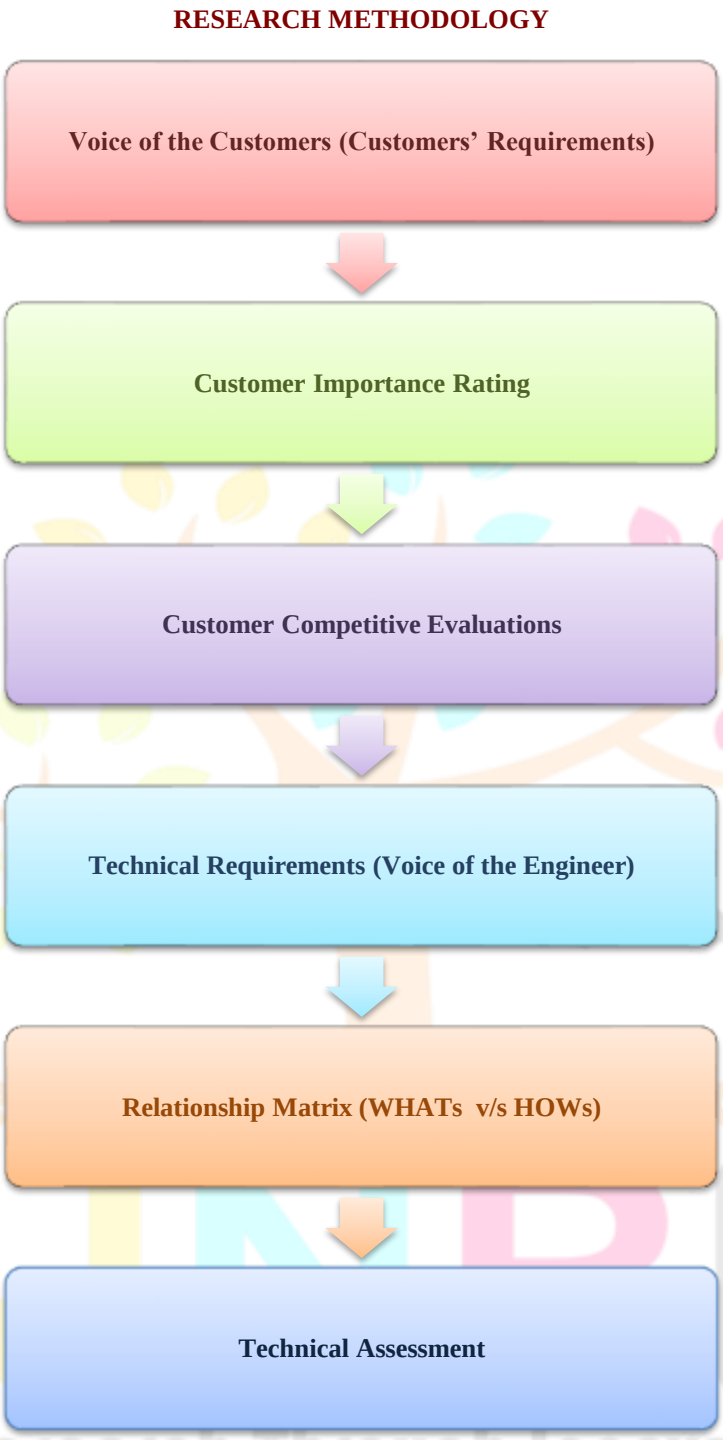

FIG. 3: Case Study – Research Methodology

Survey

Research Method	:	Quantitative Survey with Structured Questionnaire
Sampling Technique	:	Convenience Sampling
Population Size	:	Large / Unknown
Sample Size	:	140
Confidence Level	:	95 %
Confidence Interval	:	8.3 %
Total Response	:	160
Incomplete / Rejected Responses	:	20
Acceptable Response	:	160 - 20 = 140
Contact	:	E-mail, Face Book, Personal & Friends' Contacts
Software	:	Minitab, MS Office Excel, Sample Size Calculator

Assumptions

1. *The Market Survey results are accurate.*
2. *Customer Requirements remain stable during the whole process.*

Table: 1 Customer Importance Rating Analysis (Crisp Model)

Sr. No.	Customer Requirements	Mean	Standard Deviation
1	Adjustable Shelves	4.19	0.84
2	Anti-Bacteria Gasket	4.36	0.90
3	Automatic Defrosting	4.34	0.87
4	Both - Legs and Adjustable Rollers / Wheels at Bottom	3.14	1.19
5	Coil Free / Clean Back Refrigerator	3.39	1.12
6	Deodorizer	4.07	0.93
7	Digital Clock on the Outside of Door	2.14	1.02
8	Door Cooling for Uniform Cooling	3.31	0.99
9	Door Handle Design	2.79	1.16
10	e – Light at Outside Door	2.73	1.15
11	FM Radio at Outside of Door	1.83	1.08
12	Freezer Lamp in the Freezer Section / Freezer Interior Light	3.25	1.02
13	Freezer Shelving	3.48	0.88
14	Hands-Free Door Opening	2.43	1.22
15	Ice Dispenser	3.20	1.18
16	Ice Twister & Ice Collector	3.56	1.10
17	LED Lighting	2.89	1.17
18	Open Door Alarm	3.41	1.25
19	Option to Customize Color	3.24	1.17
20	Preserve - Food & Freshness	4.48	0.90
21	Quick Ice Making	3.96	0.90
22	Scratch Free Surface	3.70	0.99
23	Separate Provision for Medical and Beauty Care Products	3.49	1.23
24	Stylish Look / Appearance	3.58	1.03
25	Temperature Setting Digital Indicator	3.75	1.04
26	Toughened Glass Shelves	3.44	1.14
27	Varieties of Model	3.38	1.01
28	Vegetable Box / Container with partition for different Vegetables	4.04	1.03
29	Warranty Period	4.50	0.84
30	Water Dispenser	3.54	1.15

Table: 2 Customer Importance Rating Analysis (Fuzzy Model)

Sr. No.	Customer Requirements	Mean	Standard Deviation
1	Adjustable Shelves	7.17	1.50
2	Anti-Bacteria Gasket	7.45	1.60
3	Automatic Defrosting	7.40	1.55
4	Both - Legs and Adjustable Rollers / Wheels at Bottom	5.27	2.21
5	Coil Free / Clean Back Refrigerator	5.73	2.07
6	Deodorizer	6.96	1.69
7	Digital Clock on the Outside of Door	3.43	1.86
8	Door Cooling for Uniform Cooling	5.60	1.87
9	Door Handle Design	4.63	2.16
10	e – Light at Outside Door	4.51	2.14
11	FM Radio at Outside of Door	2.91	1.95
12	Freezer Lamp in the Freezer Section / Freezer Interior Light	5.46	1.92
13	Freezer Shelving	5.92	1.66
14	Hands-Free Door Opening	3.97	2.25
15	Ice Dispenser	5.36	2.19
16	Ice Twister & Ice Collector	6.06	2.04
17	LED Lighting	4.80	2.18
18	Open Door Alarm	5.75	2.29
19	Option to Customize Color	5.46	2.17
20	Preserve - Food & Freshness	7.64	1.60
21	Quick Ice Making	6.77	1.63
22	Scratch Free Surface	6.29	1.83
23	Separate Provision for Medical and Beauty Care Products	5.89	2.26
24	Stylish Look / Appearance	6.08	1.90
25	Temperature Setting Digital Indicator	6.38	1.90
26	Toughened Glass Shelves	5.81	2.10
27	Varieties of Model	5.70	1.90
28	Vegetable Box / Container with partition for different Vegetables	6.88	1.86
29	Warranty Period	7.67	1.49
30	Water Dispenser	5.99	2.11

Table: 3 Crisp and Triangular Fuzzy Numbers

LINGUISTIC VARIABLE	SYMBOL	CRISP NUMBER	FUZZY NUMBER
Very Low Importance	VL	1	(1,1,3)
Low importance	L	2	(1,3,5)
Medium Importance	M	3	(3,5,7)
High Importance	H	4	(5,7,9)
Very High Importance	VH	5	(7,9,9)

Table: 4 Top Priority Customer Requirements

Sr. No.	Customer Requirements
1	Warranty Period
2	Preserve - Food & Freshness of Fruits / Vegetables
3	Anti-Bacteria Gasket
4	Automatic Defrosting
5	Adjustable Shelves
6	Deodorizer
7	Vegetable Box with partition for different Vegetables / Fruits
8	Quick Ice Making
9	Digital Temperature Setting / Display
10	Scratch Free Surface
11	Stylish Look / Appearance
12	Freezer Shelving

Table: 5 Customer Competitive Evaluations (Crisp Model)

Customer Requirements	Customer Importance Rating	Our product	Competitor 1	Competitor 2	Target of Improvement	Improvement Factor	Sales point	Absolute weight	Demanded Quality Weight (%)
Warranty Period	4.50	4.14	4.00	3.63	5	1.21	1.2	6.52	9.87
Preserve - Food & Freshness	4.48	4.07	4.10	3.88	5	1.23	1.2	6.60	9.99
Anti-Bacteria Gasket	4.36	3.36	3.60	3.75	4	1.19	1.1	5.72	8.66
Automatic Defrosting	4.34	3.79	3.60	3.50	4	1.06	1.2	5.50	8.32
Adjustable Shelves	4.19	3.36	3.60	3.50	4	1.19	1.0	5.00	7.56
Deodorizer	4.07	3.14	3.20	3.75	4	1.27	1.1	5.70	8.63
Vegetable Box with partition	4.04	3.21	3.80	3.38	4	1.24	1.0	5.02	7.60
Quick Ice Making	3.96	3.14	3.70	3.50	4	1.27	1.2	6.04	9.15
Digital Temperature Setting	3.75	2.50	2.30	3.63	4	1.60	1.1	6.60	9.99
Scratch Free Surface	3.70	2.71	3.30	3.63	4	1.47	1.0	5.45	8.25
Stylish Look / Appearance	3.58	3.71	3.40	4.00	4	1.08	1.1	4.24	6.42
Freezer Shelving	3.48	3.79	3.30	3.63	4	1.06	1.0	3.68	5.56

Table: 6 Customer Competitive Evaluations (Fuzzy Model)

Customer Requirements	Customer Importance Rating	Our product	Competitor 1	Competitor 2	Target of Improvement	Improvement Factor	Sales point	Absolute weight	Demanded Quality Weight (%)
Warranty Period	6.01 8.00 8.66	5.29 7.29 8.71	5.00 7.00 8.60	4.25 6.25 8.00	7 9 9	1.32 1.24 1.03	5 7 9	39.82 69.18 80.47	12.48
Preserve - Food & Freshness	6.01 7.96 8.64	5.14 7.14 8.71	5.20 7.20 8.60	4.75 6.75 8.25	7 9 9	1.36 1.26 1.03	5 7 9	40.93 70.18 80.34	12.68
Anti-Bacteria Gasket	5.77 7.73 8.59	3.71 5.71 7.57	4.20 6.20 8.00	4.50 6.50 8.25	5 7 9	1.35 1.23 1.19	3 5 7	23.31 47.34 71.44	8.65
Automatic Defrosting	5.69 7.67 8.56	4.71 6.57 7.57	4.20 6.20 7.60	4.25 6.00 7.50	5 7 9	1.06 1.07 1.19	5 7 9	30.15 57.20 91.55	10.79
Adjustable Shelves	5.39 7.39 8.51	3.71 5.71 7.43	4.20 6.20 8.20	4.00 6.00 7.75	5 7 9	1.35 1.23 1.21	1 3 5	7.25 27.14 51.58	4.68
Deodorizer	5.17 7.14 8.37	3.43 5.29 7.00	3.40 5.40 7.40	4.50 6.50 8.25	5 7 9	1.46 1.32 1.29	3 5 7	22.63 47.30 75.34	8.69
Vegetable Box with partition	5.13 7.07 8.26	3.43 5.43 7.00	4.60 6.60 8.00	4.00 5.75 7.25	5 7 9	1.46 1.29 1.29	1 3 5	7.48 27.36 53.08	4.77
Quick Ice Making	4.97 6.91 8.30	3.43 5.29 7.00	4.40 6.40 8.00	4.25 6.00 7.50	5 7 9	1.46 1.32 1.29	5 7 9	36.04 64.10 96.04	12.12
Digital Temperature Setting	4.57 6.50 7.93	2.57 4.00 5.71	2.40 3.60 5.60	4.50 6.25 7.75	5 7 9	1.94 1.75 1.58	3 5 7	26.67 56.88 87.41	10.31
Scratch Free Surface	4.44 6.40 7.91	2.86 4.43 6.14	3.60 5.60 7.40	4.25 6.25 7.75	5 7 9	1.75 1.58 1.47	1 3 5	7.78 30.35 57.98	5.21
Stylish Look / Appearance	4.23 6.16 7.77	4.43 6.43 8.29	3.80 5.80 7.60	5.00 7.00 8.75	5 7 9	1.13 1.09 1.09	3 5 7	14.32 33.52 59.09	6.16
Freezer Shelving	4.00 5.96 7.76	4.71 6.57 7.86	3.80 5.60 7.40	4.50 6.25 7.75	5 7 9	1.06 1.07 1.15	1 3 5	4.24 19.04 44.43	3.45

Table: 7 Rank of Technical Requirements (Crisp Model)

Rank	Technical Requirements
1	Sensor Technology
2	Refrigerator Temperature Variation
3	Refrigerator On-Off Cycle
4	Failure Rate
5	Refrigerator Cooling Speed
6	Anti-fungal Door Gasket Material
7	Surface Treatment
8	Compressor Warranty
9	Modular Shelves
10	Insulation Efficiency
11	Interior Look
12	Carbon based Deodorizer
13	Multi Air Flow Cooling System
14	Refrigerator Body Attributes
15	Freezer Dimensions
16	Specially Designed Ice Trays
17	Vegetable Separator
18	Air Filtration
19	Designer Handle

Table: 8 Rank of Technical Requirements (Fuzzy Model)

Rank	Technical Requirements
1	Sensor Technology
2	Refrigerator Temperature Variation
3	Multi Air Flow Cooling System
4	Insulation Efficiency
5	Refrigerator On-Off Cycle
6	Failure Rate
7	Refrigerator Cooling Speed
8	Anti-fungal Door Gasket Material
9	Compressor Warranty
10	Specially Designed Ice Trays
11	Interior Look
12	Air Filtration
13	Vegetable Separator
14	Surface Treatment
15	Carbon based Deodorizer
16	Refrigerator Body Attributes
17	Modular Shelves
18	Freezer Dimensions
19	Designer Handle

6. CONCLUSION

In this paper, we have examined the possibility to use QFD as a product development tool by using two different QFD model. A case study has been carried out for Domestic Refrigerator (Direct Cool type). QFD models with different approaches links customer requirements or "whats" with the technical requirements or "hows", so the voice of the customer is translated into voice of engineers. To eliminate the shortcomings in a crisp (traditional) QFD model, a fuzzy QFD model is used. Fuzzy evaluation procedures can reflect the uncertain issues inherent from common linguistic assessment. Subtle differences among customers can also be easily discriminated.

The above results and discussion lead us towards a very sharp conclusion that Fuzzy QFD can be said as one of the best technique to carry out a broad analysis of what customers need in a consumer product and how we can make it possible and feasible worth to be manufactured so that customers mat get maximum satisfaction. The product is designed according to the customer requirements and so having a very good market. The product is compared with the other benchmarking manufacturers and so all competitive aspects are included.

Ultimately we can say that Fuzzy QFD approach improves the consumer product design, very much efficient and in accurate way, than the Crisp QFD approach.

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