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CUSTOMER PERCEIVED QUALITY IMPROVEMENT OF SYNTHETIC FIBER USING FUZZY QFD: A CASE STUDY

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Abstract: *The performance of the ready-made garment (RMG) industry has been one of the most notable success stories of the Bangladesh economy over two decades. To meet the growing demand of synthetic yarns, Bangladesh has to import it from foreign countries which cost a substantial amount of foreign currency for the country. It is a pressing need for local manufacturers to come forward, produce quality synthetic yarn and fulfill the demand of the local market. The purpose of this paper is to present a Fuzzy Quality Function Deployment (FQFD) model to indentify customer requirements and also demonstrate how these requirements can be used to prioritize the design requirements for manufacturing of synthetic yarns. In this system, 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 and as a result customer perceived quality will soar.*
Keywords: *Customer Satisfaction, Fuzzy Quality Function Deployment (FQFD), House of Quality (HOQ).*

1. INTRODUCTION

The ready-made garment (RMG) industry of Bangladesh started in the late 1970s and became a prominent player in the economy within a short period of time. A huge 76 per cent of the export earnings of the country come from textile and clothing exports. The most important export markets are the United States and the EU. The performance of the ready-made garment (RMG) industry has been one of the most notable success stories of the Bangladesh economy over two decades. Bangladesh is the sixth-largest exporter of clothing in the world after China, the EU, Hong Kong, Turkey, and India. The total market size of Bangladesh's textile and clothing industry was EUR 9 billion in 2008. Nearly 100% of industry exports consist of garments as the textile sector supplies the domestic garment industry (Haider 2007).

The explosive growth of the RMG industry in the country has not been supported by the growth of backward linkage facilities. Based on Bangladesh Garment Manufacturers and Exporters Association (BGMEA) data, current yarn production satisfied only 22 % of the total yarn demand. The principal materials used in the spinning sub-sector are raw cotton and synthetic fibers such as viscose and polyester staple fibers. None of these materials, however, are produced in Bangladesh on a large enough scale to supply a significant part of the demand. The demands of synthetic yarns are increasing day by day both in the United State Sates and worldwide. The term synthetic describes any manufactured fiber made from chemical synthesis. The most common synthetic fibers in the 20th century are nylon, polyester, acrylic, and polyurethane. The industry under consideration manufactures synthetic textured yarn. The use of polyester filament yarn is growing rapidly throughout Bangladesh. In normal year of operation the industry contributes Tk. 370.15 million to the country's national Gross Domestic Product (GDP) (BGMEA Website). To meet the growing demand of synthetic yarns, Bangladesh has to import it from foreign countries which cost a substantial amount of foreign currency for the country. It is a pressing need for local manufacturers to come forward, produce quality synthetic yarn and fulfill the demand of the local market. This paper demonstrates the use of Fuzzy Quality Function Deployment to indentify customer requirements and also shows how these requirements can be used to prioritize the design requirements for manufacturing of synthetic yarns.

In a market with fierce competition, and rapid changes of customer orientation, only the effective delivery of service quality can enhance corporate profit and competitiveness (Fonseca et al. 2010). Thus, how to use product quality to enhance customer value becomes an important issue in the manufacturing of synthetic yarn in Bangladesh. Marketing researchers have, for a long time, recognized the importance of service quality as well as consumer satisfaction. Significant investigation has been conducted in both fields (Friman et al. 2001; Higgs et al. 2005). However, few studies have explored the both sides of the service process: operations (the internal side) and customer (the external side) perspectives of quality and satisfaction (Zhu et al.

2010). Now-a-days manufacturing industries are looking for changing their business operations from a product oriented approach to marketing - oriented approach in order to meet the expectations of customers and long term success in the competitive business environment (Lai 2003). As quality is defined as fulfilling of customer needs, the customer needs of the product play an important role in customer satisfaction. Therefore, it is essential to adopt a customer - focused design approach for developing products and services to meet the expectations of the customer.

Quality Function Deployment (QFD) is one of the Total Quality Management quantitative tools and techniques that could be used to translate customer requirements and specifications into appropriate technical or service requirements (Baba et al. 2009). QFD originated in 1972 in Japan, has been a successful tool to assist the quality improvement team systematically in translating market research and customer requirements into the technical requirements to satisfy customer. In QFD, the customer requirement planning matrix, also known as "house of quality" (HOQ), is the first step in investigating customer needs and market requirements. HOQ begins with customer requirements (CRs) which are usually obtained from market survey or customer interview. The acquired CRs are translated into a list of measureable ECs. Based on the acquired CRs and ECs, the product development team can determine the relationships between CRs and ECs, the competitive analysis, and the correlations between ECs. The obtained information can be used to calculate the importance of ECs (Cohen 1995; Curcic and Milunovic 2007; Prasad et al. 2010). The components of HOQ are illustrated in Figure 1.

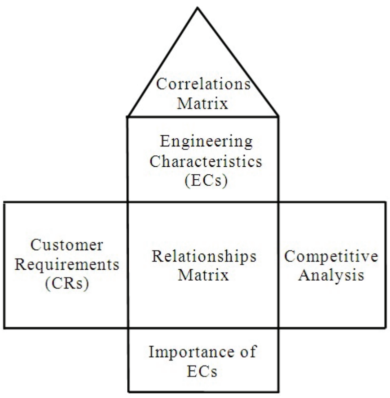


Figure 1: Components of HOQ

The fundamental rationale of HOQ is introduced in several publications (Cohen 1995; Revelle et al. 1998). Manikandan et al. (2009) has applied QFD to design an economic sampling plan for textile sector. Hergeth (2001) has developed QFD matrix for synthetic particle board. QFD also has been successfully implemented in many industries worldwide.

Although QFD is widely used in the different manufacturing companies, the traditional methodology has certain shortcomings. When there is a single customer group for a product, the designers can easily find the appropriate technical requirements for the product development. If the different customer groups have similar needs for the same product, the implementation of traditional HOQ is easier as the importance ratings of the customer needs are almost unique. But, sometimes for the same product there are different customer groups and they may have different needs. The importance ratings of customer needs are also different for different customer groups. The process of dividing total market into market groups consisting of individuals whose characteristics are relatively homogeneous within each set is termed as market segmentation. The market segmentation issue is not addressed in the traditional HOQ. Prioritization of customer needs is critical, since design of products and services with QFD will be driven to fulfill these prioritized needs (Enriquez et al. 2004).

A number of scholars have applied the fuzzy set theory to QFD and developed various fuzzy QFD approaches to overcome the shortcomings of the traditional QFD. For example, Khoo and Ho (1996) proposed the concept of fuzzy QFD and fuzzified linguistic variables to make them more reasonable. Besides, they also considered the correlations among CRs and the correlations among ECs. Chan, et al. (1999) applied fuzzy number and entrophy methods to derive the importance of CRs, respectively, and combined the results to obtain the final importance of CRs. Wang (1999) viewed QFD as a multi-criteria decision making problem and developed a new fuzzy outranking method to obtain the importance ranking of ECs. Shen et al. (2001) found it necessary to translate customer requirements into trends of future analysis. They added a future tendency index to the importance of CRs to compute the final importance of CRs. Shen et al. (2001) mentioned that the importance ranking of ECs may be affected by several factors, including types of fuzzy numbers, defuzzification methods, and the number of fuzzy numbers. Sohn and Choi (2001) applied fuzzy QFD to supply chain and included reliability in the assessment. Büyüközkan et al. (2004) established a network hierarchy based on the QFD framework and employed fuzzy extent analysis to calculate the weight of each pairwise comparison matrix. The results were later integrated into a super matrix to compute the importance of ECs. Bottani and Rizzi (2006) applied QFD in logistics and supply chain management. They translated linguistic values of customer requirements into fuzzy numbers and computed the importance of ECs using the conventional QFD method. In this paper we will use Fuzzy QFD to prioritize the design requirements of the company and as a result will make the product more responsive to customers.

2. OBJECTIVES

The objective of this paper is to address the challenge of developing a fuzzy QFD system to improve the customer perceived quality of synthetic fibers. To efficiently handle the fuzziness in human judgment and preference, the linguistic variables characterized by triangular fuzzy numbers are used to describe the fuzzy relationship strength between customer needs and technical requirements. The research objective are, first, to adopt House of Quality (HOQ) to provide a systematic and structured method to support the integrated decision-making process ; second, to integrate fuzzy set theory into HOQ to facilitate the processing of quality improvement relevant QFD information. The FQFD model can assist decision-makers to find the priorities of customer need attributes and requirements for the improvement of customer perceived quality of synthetic fibers.

3. FUZZY QUALITY FUNCTION DEPLOYMENT MODEL

3.1 Fuzzy set theory

Zadeh (1965) came out with the fuzzy set theory to deal with vagueness and uncertainty in decision making in order to enhance precision. Thus the vague data may be represented using fuzzy numbers, which can be further subjected to mathematical operation in fuzzy domain. Thus fuzzy numbers can be represented by its membership grade ranging between 0 and 1. A triangular fuzzy number (TFN) $\tilde{M}$ is shown in Figure 2.

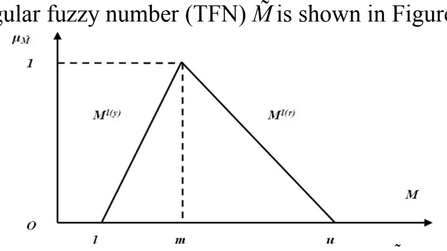


Figure 2: Triangular fuzzy number $\tilde{M}$

A TFN is denoted simply as (l/m, m/u) or (l, m, u), represents the smallest possible value, the most promising value and the largest possible value respectively. The TFN having linear representation on left and right side can be defined in terms of its membership function as:

$$\mu(x|\tilde{M}) = \begin{cases} 0, & x < l, \\ (x-l)/(m-l), & l \le x \le m\ l, \\ (u-x)/(u-m), & m \le x \le u, \\ 0, & x > u, \end{cases} \quad (1)$$

A fuzzy number with its corresponding left and right representation of each degree of membership is as below:

$$\tilde{M} = (M^{l(y)}, M^{l(r)}) = (l+(m-l)\,y,\ u+(m-u)\,y),\ y\ \varepsilon[0,1] \quad (2)$$

where $l(y)$ and $l(r)$ denotes the left side representation and the right side representation of a fuzzy number respectively.

The fuzzy summation $\oplus$ and fuzzy subtraction **Θ** of any two TFN is also TFNs, but the multiplication $\otimes$of any two TFNs is only approximate TFNs. The data can be assessed using

If $\tilde{M}_1 = (a_1, b_1, c_1)$ and $\tilde{M}_2 = (a_2, b_2, c_2)$ are two TFNs, then their operational laws can be expressed as follows:

$$\tilde{M}_1 \oplus \tilde{M}_2 = a_1 + a_2, b_1 + b_2, c_1 + c_2 \quad (3)$$

$$\tilde{M}_1 \Theta \tilde{M}_2 = a_1 - a_2, b_1 - b_2, c_1 - c_2 \quad (4)$$

$$\tilde{M}_1 \otimes \tilde{M}_2 = a_1a_2, b_1b_2, c_1c_2 \quad (5)$$

$$\lambda \otimes \tilde{M}_1 = \lambda a_1, \lambda b_1, \lambda c_1 \text{ where } \lambda > 0, \lambda \in \quad (6)$$

$$\tilde{M}_1^{-1} = (1/c_1, 1/b_1, 1/a_1) \quad (7)$$

3.2 Outline of the Fuzzy Quality Function Deployment Model

To efficiently identity customer requirements for quality improvement in a fuzzy environment, a systematic procedure of the FQFD model is proposed. A stepwise description of the FQFD model can be summarized as follows:

- **Step 1:** Identify customer needs to enhance service quality.
- **Step 2:** Measure the importance level of each customer needs to reflect the voice of customer service quality requirements.
- **Step 3:** Calculate the priorities of customer needs.
- **Step 4:** Develop design or engineering requirements to represent the service provider's responses to the customer quality requirements.
- **Step 6:** Construct the central relationship matrix to link the design or engineering requirements to customer needs or requirements.
- **Step 7:** Determine the fuzzy relationship strength of each design or engineering requirements and each customer needs or requirements.
- **Step 8:** List the engineering requirements' ranking to identify the priority that each design or engineering requirements has in order to satisfy the overall customer service quality requirements.

4. EMPIRICAL ANALYSIS

In this section, customer perceived quality improvement of Beximco Synthetics Ltd. (BSL) is used as an empirical example to demonstrate the computational process of the proposed FQFD model. Beximco Synthetics Ltd. (BSL) is currently working on raising the customer satisfaction level and quality of service in order to increase their market share.

4.1 Classifying Customer Groups

There is a strong correlation among the quality of service, the level of customer satisfaction and the profitability for the company. Higher standards of quality lead to higher levels of satisfaction in the customers, which at the same time increase the possibility of higher prices and frequently, lower costs. Thus quality is a strategic variable that can provide the company with a competitive advantage (Kotler 2004). But the level of customer satisfaction can be significantly different for different customer groups. So, it is very important to divide the customers into relevant groups. For Beximco Synthetics Ltd. (BSL) this grouping is done according to the type of customers. Figure 3 represents the consumer mix of BSL in 2010

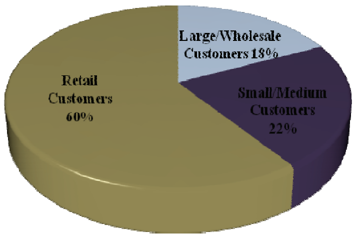


Figure 3: Consumer mix of BSL in 2010

4.2 Questionnaire Development

After summarizing this previous body of literatures review and conducting personal interviews with experts, senior managers of several textile industries and 31 attributes were selected for use in the questionnaire survey. After the first draft of the questionnaire was designed, several experts in the field were asked to give their views on the questionnaire content. After receiving their comments the questionnaire was revised and finalized with 17 attributes.

4.3 Identifying Customer Demand

This stage includes two steps. In order to identify customer needs, in the first step, customers are interviewed and their expectations are captured directly from a market survey, e.g. personal interview, focus group discussion and questionnaire survey. In the second step, analysis is done to find out the percentage of customers mentioned these requirements. Table 1 shows summary of survey report for different customers' demand.

A reliability test, validity test, and correlation analysis were conducted to assess whether the customer need dimensions were reliable and valid. The questionnaire's reliability was also tested by the most commonly used statistical coefficient, Cronbach's α. If its value was between 0.70 - 0.98, the questionnaire's content was considered highly reliable. All customer's need or requirements level were well above 0.94, considered excellent for a satisfactory level of reliability in basic research (Sekaran, 1992). The validity of the questionnaire's construction was tested according to Kerlinger (1973) who proposed a part-whole correlation test. In total, three attributes correlation coefficients were smaller than 0.5, therefore were not available for this test and were subsequently deleted.

Table1: Summary of survey report for different customers' demand

No.	Demand	Rate (%)
1	No broken filament	80
2	Continuous market supply	65
3	Reasonable cost	56
4	Package weight	55
5	No weak yarn	50
6	Package soldering angle	49
7	Information collection from market by electronic medium	48
8	Avoid Roto mistake	48
9	Uniform length of bobbin	47
10	No change in bobbin Color	46
11	Cross winding	42
12	Shining yarn	41
13	Tight winding	40
14	No loose winding	40
15	Option to change yarn	38
16	Avoid CLQ yarn	32
17	Marketing officer appointed	25

4.4 Classifying Customer Expectations

Once the requirements and their ratings are obtained, multiple regressions is used to obtain the level of importance of the customer expectations. A scale of 0 to 80 is used to find the weights of the customer requirements. Fuzzy linguistic terms are used to assign the importance of customer requirements and strengths of design characteristics' contributions to customer requirements. Triangular fuzzy numbers are utilized to capture the vagueness of fuzzy linguistic terms and represent the subjective and conflicting assessment of design team members. The computational procedure for using fuzzy numbers in the fuzzy QFD system is introduced in the following:

Step 1: assigning linguistic terms. Design team members can assign the linguistic terms (Figure 4), such as 'very high' for determining importance of customer requirements.

Step 2: translating the linguistic terms into triangular fuzzy numbers (Table 2). For instance, (0.9, 1, 1) represent the triangular fuzzy scale for 'very high' 'important'

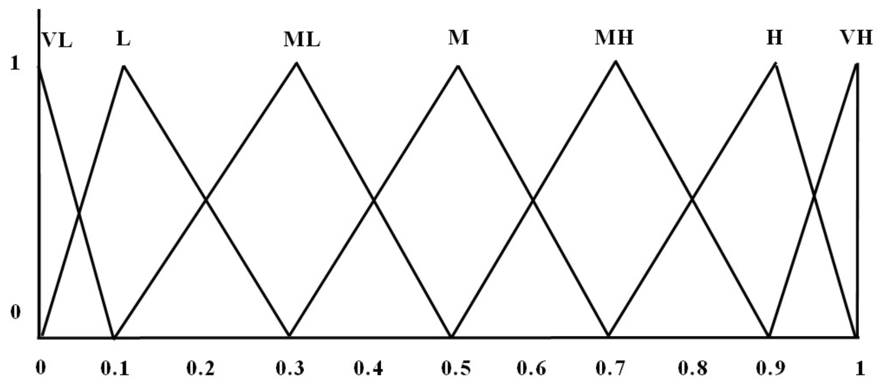


Figure 4: Fuzzy triangular membership functions for weights of the customer requirements

Table 2: Linguistic variable and the fuzzy scale for describing weight of the criteria

Linguistic scale for importance	Membership function	Domain	Triangular fuzzy scale (*l, m, u*)
Very Low (VL)	$\mu_M(x) = (0.1-x)/(0.1-0)$	$0 \le x \le 0.1$	(0,0,0.1)
Low (L)	$\mu_M(x) = (x-0)/(0.1-0)$	$0 \le x \le 0.1$	(0,0.1,0.30)
	$\mu_M(x) = (0.3-x)/(0.3-0.1)$	$0.1 \le x \le 0.3$	
Medium Low (ML)	$\mu_M(x) = (x-0.1)/(0.3-0.1)$	$0.1 \le x \le 0.3$	(0.1,0.3,0.5)
	$\mu_M(x) = (0.5-x)/(0.5-0.3)$	$0.3 \le x \le 0.5$	
Medium (M)	$\mu_M(x) = (x-0.3)/(0.5-0.3)$	$0.3 \le x \le 0.5$	(0.3,0.5,0.7)
	$\mu_M(x) = (0.7-x)/(0.7-0.5)$	$0.5 \le x \le 0.7$	
Medium High (MH)	$\mu_M(x) = (x-0.5)/(0.7-0.5)$	$0.5 \le x \le 0.7$	(0.5,0.7,0.9)
	$\mu_M(x) = (0.9-x)/(0.9-0.7)$	$0.7 \le x \le 0.9$	
High (H)	$\mu_M(x) = (x-0.7)/(0.9-0.7)$	$0.7 \le x \le 0.9$	(0.7,0.9,1)
	$\mu_M(x) = (1-x)/(1-0.9)$	$0.9 \le x \le 1$	
Very High (VH)	$\mu_M(x) = (x-1)/(1-0.9)$	$0.9 \le x \le 1$	(0.9,1,1)

Table 3, 4 and 5 shows the weighted requirements and converted fuzzy scale for large customers, small-medium customers and retail customers respectively.

Table 3: Customer requirements for large customers

No.	Requirements	Weights	Importance	Fuzzy Scale
1	No broken filament	80	1	VH
2	Continuous market supply	68	0.85	H
3	Package weight	55	0.68	MH
4	Information collection from market by electronic medium	45	0.56	M

Table 4: Customer requirements for small-medium customers

No.	Requirements	Weights	Importance	Fuzzy Scale
1	No broken filament	70	0.87	H
2	No weak yarn	60	0.75	MH
3	Continuous market supply	55	0.68	MH
4	Tight winding	40	0.50	M
5	Cross winding	25	0.31	ML
6	Avoid Roto mistake	20	0.25	ML
7	Bobbin color should not mix	15	0.18	L

Table 5: Customer requirements for retail customers

No.	Requirements	Weights	Importance	Fuzzy Scale
1	No broken filament	80	1	VH
2	Continuous market supply	68	0.85	H
4	Bobbin colors should not mix	55	0.68	MH
5	Weak yarns should be avoided	51	0.63	MH
6	Cost should be feasible	47	0.58	M
7	Avoid Roto mistake	45	0.56	M
8	Package weight	35	0.43	M
9	Cross winding	28	0.35	ML
10	Tight winding	25	0.31	ML
11	Flexible bobbin length and soldering angle	22	0.27	ML
12	Shining Yarn	22	0.27	ML
13	Loose windings should be avoided	20	0.25	ML

4.5 Establishing design requirements to meet the customer requirements

This part of the progress, as stated by Knowles, is often the most time consuming and difficult, as it involves the experts exploring their knowledge and experience in order to establish the design requirements to meet the customer requirements. Design requirements are developed on the basis of the company's managerial resources or organizational characteristics, which can be utilized to improve customers' satisfaction. These requirements can be grouped by consultation of experts or executive managers' brainstorming. Tables 6, 7 and 8 shows the design requirements needed to fulfill large customers, small-medium customers and retail customer requirements respectively

.

Table 6: Design requirements for large customers

No.	Expectations(What's)	Design Requirements(How's)
1	Broken Filament	Spinneret
		Continuous power supply
		Electric Heater for machines
		Skilled manpower
2	Continuous market supply	Proper utility support
		All data collect digitally
		Time to time communication to customer
3	Package weight	Closed supervision by production officer
		Travers Guide
4	Information collect from market by electronic media	Trained marketing officer

Table 7: Design requirements for small-medium customers

No.	Expectations(What's)	Design Requirements (How's)
1	No broken filament	Spinneret
		Continuous power supply
		Electric Heater for machine
		Skilled manpower
2	Continuous market supply	Proper utility support
		All data collect digitally
		Time to time communication to customer
3	Bobbin color should be different	Closed supervision by production officer
4	Weak yarns should be avoided	Cooling oil
5	Avoid Roto mistake	Air pressure for intermingle yarn
		Belt and Pulley
6	Cross winding	Travers guide
7	Tight winding	Belt and Pulley
		Trained production officer

Table 8: Design requirements for retailers

No.	Expectations(WHATs)	Internal quality indicators
1	No broken filament	Spinneret
		Continuous power supply
		Electric heater for machine
		Skilled manpower
2	Continuous market supply	Proper utility support
		Electronic collection of data
		Responsiveness to customer
3	Package weight	Travers guide
4	Bobbin color should be different	Closed supervision by production officer
5	Weak yarns should be avoided	Cooling oil
6	Roto mistake	Air pressure for intermingle yarn
		Belt and Pulley
7	Cross winding	Travers guide
8	Tight winding	Belt and Pulley
		Trained production officer
9	Bobbin length and soldering angle	Travers guide
		Skilled machine operator
10	Cost should be feasible	Always communication to market for others prize
11	Shining	Cooling oil

4.6 Building QFD Matrix

At this stage, we will try to build relationships between customer requirements and design requirements. Personal interviews have therefore been held with some professionals from Beximco Synthetics Ltd. (BSL) who was asked to assess the relationships between the customer requirements and the design requirements. The relationships between the customer requirements and design requirements are established; by means of fuzzy numbers and fuzzy membership functions which have been shown are Figure 5 and Table 9.

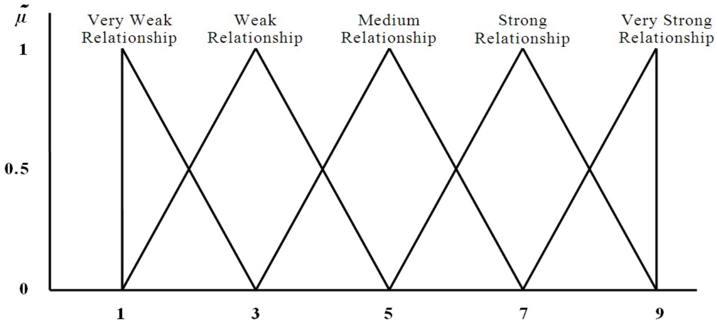
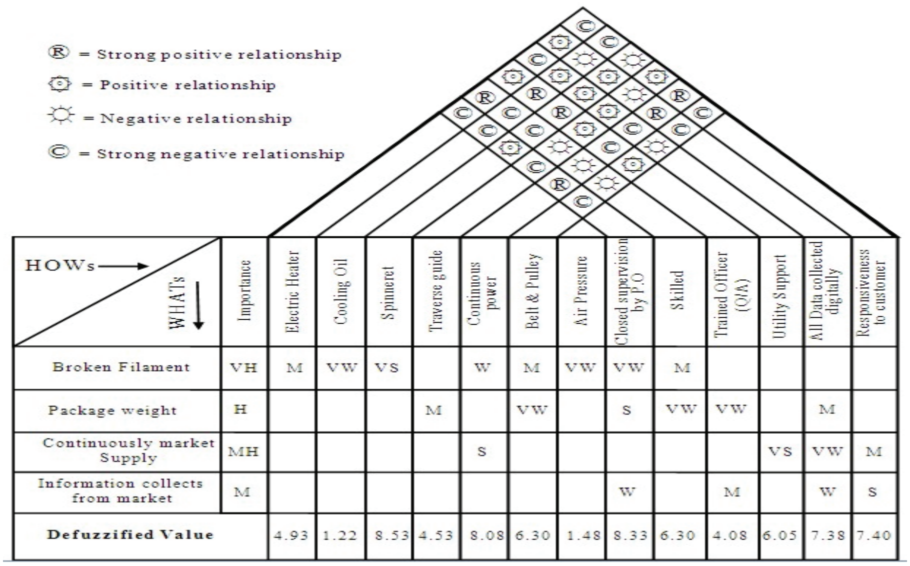


Figure 5: Fuzzy triangular membership functions for interrelationship matrix

Table 9: Linguistic variables and fuzzy scale for interrelationship matrix

Linguistic scale for importance	Fuzzy numbers	Membership function	Domain	Triangular fuzzy scale (l, m, u)
Very Weak Relationship (VW)	$\tilde{1}$	$\mu_M(x) = (3-x)/(3-1)$	$1 \le x \le 3$	(1, 1, 3)
Weak Relationship (W)	$\tilde{3}$	$\mu_M(x) = (x-1)/(3-1)$	$1 \le x \le 3$	(1, 3, 5)
		$\mu_M(x) = (5-x)/(5-3)$	$3 \le x \le 5$	
Medium Relationship (M)	$\tilde{5}$	$\mu_M(x) = (x-3)/(5-3)$	$3 \le x \le 5$	(3, 5, 7)
		$\mu_M(x) = (7-x)/(7-5)$	$5 \le x \le 7$	
Strong Relationship (S)	$\tilde{7}$	$\mu_M(x) = (x-5)/(7-5)$	$5 \le x \le 7$	(5, 7, 9)
		$\mu_M(x) = (9-x)/(9-7)$	$7 \le x \le 9$	
Very Strong Relationship (VS)	$\tilde{9}$	$\mu_M(x) = (x-7)/(9-7)$	$7 \le x \le 9$	(7, 9, 9)

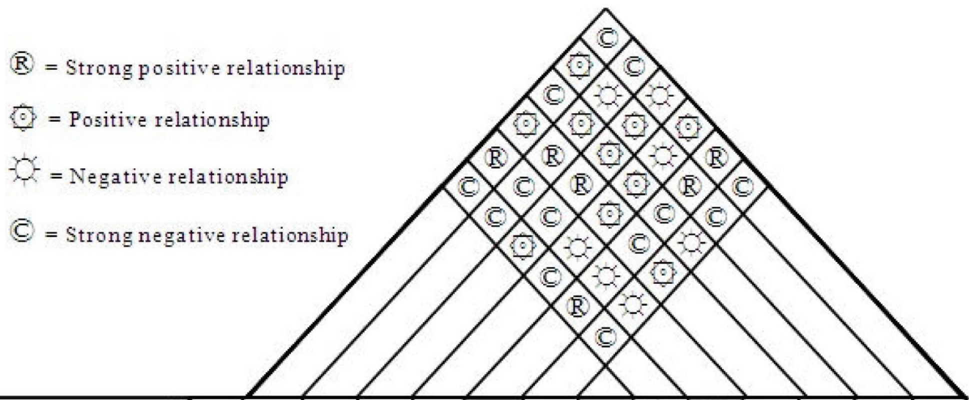
Source: Bozbura and Beskese (2007)



HOWs → / WHATs ↓	Importance	Electric Heater	Cooling Oil	Spinneret	Traverse guide	Continuous power	Belt & Pulley	Air Pressure	Closed supervision by P.O	Skilled	Trained Officer (Q/A)	Utility Support	All Data collected digitally	Responsiveness to customer
Broken Filament	VH	M	VW	VS		W	M	VW	VW	M				
Package weight	H				M		VW		S	VW	VW		M	
Continuously market Supply	MH					S						VS	VW	M
Information collects from market	M								W		M		W	S
Defuzzified Value		4.93	1.22	8.53	4.53	8.08	6.30	1.48	8.33	6.30	4.08	6.05	7.38	7.40

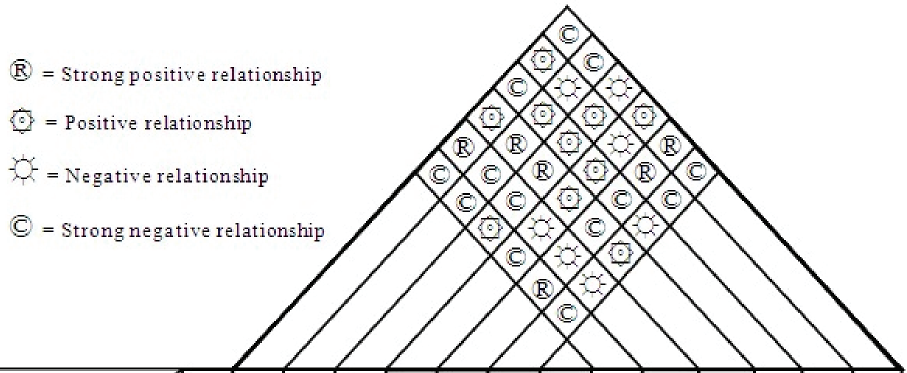
Figure 6: The QFD matrix for large customers

Relationships between design requirements are found by carrying out series of interviews with the experts. The relationships are depicted by four signs where ® indicates a strong positive relationship, ۞ indicates a positive relationship, ☼ indicates a negative relationship, © a strong negative relationship. HOQ matrix is then developed for three customer groups by placing these relationships in appropriate boxes. Figure 6, 7 and 8 shows HOQ matrix for large, small-medium and retail customers respectively.



HOWs → / WHATs ↓	Importance	Electric Heater	Cooling Oil	Spinneret	Traverse guide	Continuous power	Belt & Pulley	Air Pressure	Closed supervision by P.O	Skilled Manpower	Trained Officer (Q/A)	Utility Support	All Data collected digitally	Responsiveness to customer
Broken Filament	H	M		VS	VW	M	W		W	W		W	W	
Weak Yarn	MH	VS	W			W			W		W			
Tight winding	M				M		S	M	VW	M	S		W	
Cross Winding	ML				VS					VS		M	W	
Continuously market Supply	MH					S						VS	S	VS
Continuously market Supply	MH					S						VS	S	VS
Roto Mistake	ML					VW	M	S	M	W				
Bobbin should not Interchanged	L								VS	W	M	M	M	M
Defuzzified Value		10.58	2.30	7.53	6.73	12.48	7.58	5.00	8.75	9.74	6.78	11.30	11.43	6.83

Figure 7: The QFD matrix for small-medium customers



HOWs → / WHATs ↓	Importance	Electric Heater	Cooling Oil	Spinneret	Traverse guide	Continuous power	Belt & Pulley	Air Pressure	Close Supervision	Skilled Manpower	Trained Officer (Q/A)	Utility Support	All Data collected digitally	Responsiveness to customer
Broken filament	VH	M		VS	VW	S	VW	W	M	M	W	W	VW	
Weak yarn	MH	M	M			VS			W		W			
Tight winding	ML				W		S	M	VW	M	S		VW	
Loose winding	ML				M		VS	VW	W	W	S		W	
Cross winding	ML				VS				M	S		M	VW	
Cost	M							VW			VW		W	S
Continuous market supply	H					VS						S	S	VS
Roto mistake	M					W	W	S	W	W				
Shining yarn	MH								VS	VW	W	W	W	W
Bobbin color	ML	M	VS	W		VW								
Package weight	M			VW	M	W			S	M	W			
Length of bobbin and soldering angle	ML		VW		M	W	W		M	VS	VW		W	
Defuzzified Value		10.36	6.90	10.28	11.33	25.5	9.22	9.78	21.10	13.78	15.28	13.10	13.48	13.53

Figure 8: The QFD matrix for retail customers

5. RESULTS

The objective of applying fuzzy QFD is to identify the design requirements which are important to meet the customers' expectations.The most relevant design requirements for the customer segments are found by aggregating output fuzzy set and defuzzified into a single output number from the HOQ. There are various methods for defuzzification such as: centroid, bisector, middle of maximum (the average of the maximum value of the output set), largest of maximum, and smallest of maximum. In this paper, centroid defuzzification method has been used. A chart is then created in which the design requirements are sorted from largest to smallest according to their defuzzified value and weight percentage. Table 10, 11 and 12 show the weighted design requirements three customer groups. If we combine the findings of these three tables we will get the overall weight percentage that we should give to the design requirements which is shown in Table 13.

Responsiveness to customer

Table 10: Weighted design requirements for large customers

No.	Design Requirements	Defuzzified Value	Weight percentage
1	Spinneret	8.53	11.49%
2	Closed supervision by production officer	8.33	11.22%
3	Continuous power supply	8.08	10.89%
4	All data collect digitally	7.38	9.94%
5	Responsiveness to customer	7.04	9.48%
6	Skilled manpower	6.30	8.49%
7	Belt and pulleys	6.30	8.49%
8	Proper utility support	6.05	8.15%
9	Electric Heater for machine	4.93	6.64%
10	Travers guide	4.53	6.10%
11	Trained production officer	4.08	5.50%
12	Air pressure for intermingle yarn	1.48	2.00%
13	Cooling oil	1.22	1.64%

Table 11: Weighted design requirements for small-medium customers

No.	Design Requirements	Defuzzified Value	Weight percentage
1	Continuous power supply	12.48	11.66%
2	All data collect digitally	11.43	10.68%
3	Proper utility support	11.30	10.56%
4	Electric Heater for machine	10.58	9.89%
5	Skilled manpower	9.74	9.10%
6	Closed supervision by production officer	8.75	8.18%
7	Belt and pulleys	7.58	7.08%
8	Spinneret	7.53	7.04%
9	Responsiveness to customer	6.83	6.38%
10	Trained production officer	6.78	6.33%
11	Travers guide	6.73	6.29%
12	Air pressure for intermingle yarn	5.00	4.67%
13	Cooling oil	2.30	2.15%

Table 12: Weighted design requirements for retail customers

No.	Design Requirements	Defuzzified Value	Weight percentage
1	Continuous power supply	25.50	14.68%
2	Closed supervision by production officer	21.10	12.15%
3	Trained quality officer	15.28	8.80%
4	Skilled manpower	13.78	7.94%
5	Responsiveness to customer	13.53	7.80%
6	All data collect digitally	13.48	7.76%
7	Proper utility support	13.10	7.54%
8	Travers guide	11.33	6.52%
9	Electric heater for machine	10.36	5.96%
10	Spinneret	10.28	5.92%
11	Air pressure for intermingle yarn	9.78	5.63%
12	Belt and pulleys	9.22	5.31%
13	Cooling oil	6.90	3.97%

Table 13: Combined weighted design requirements

No.	Design Requirements	Weight Percentage
1	Continuous power supply	12.41
2	Closed supervision by production officer	10.52
3	All data collect digitally	9.46
4	Proper utility support	8.75
5	Skilled manpower	8.51
6	Spinneret	8.15
7	Responsiveness to customer	7.88
8	Electric Heater for machine	7.5
9	Belt and pulleys	6.96
10	Trained production officer	6.88
11	Travers guide	6.3
12	Air pressure for intermingle yarn	4.1
13	Cooling oil	2.58

It is evident from Tables 10, 11, 12 and 13 that individual design requirements priorities are significantly different than the combined design requirements priorities. It happened because requirements that satisfy one type of customer may not satisfy the other types. So it is necessary to observe tables for combined and individual requirements to decide the requirements that should be chosen for improvements.

6. CONCLUSIONS

In this paper, a fuzzy QFD system for the improvement of customer perceived quality of synthetic fibers based on the mechanisms of conventional QFD methodology and fuzzy set theory has been presented. In the conventional HOQ approach, the QFD team assigns numeric values to each of the customer needs. But QFD is primarily focused on the accurate and exact translation of customer needs into design requirements. Therefore, there exists a gap between the customers' conception and designers' conception and due to which it is difficult for designers to translate the actual needs of customers into design requirements. To eliminate the shortcomings in a traditional QFD model, a fuzzy QFD model with a linguistic certainty index is proposed in this research. Fuzzy evaluation procedures can reflect the uncertain issues inherent from common linguistic assessment. Subtle differences among candidates can also be easily discriminated. The proposed fuzzy QFD model also provides flexibility that can adopt different linguistic certainty levels by altering an index. Changing the linguistic certainty index will generate different spreads of fuzzy numbers so that a different level of linguistic certainty can be revealed. Thus, the group bias of a QFD assessment team can be properly adjusted without using unequal weights that would derail the systematic approach of QFD models. Fuzzy QFD allowed Beximco Synthetics Ltd. (BSL) to identify the design requirements that they have to focus most in order to keep their customers satisfied. Due to the customer perceived quality improvement, customer complaints are reduced significantly and as a result new opportunities open up.

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