Quality improvement of T-shirt using fuzzy QFD: a case study

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Abstract: The ready-made garment industry is one of the most successful industries in Bangladesh. Its performance is notable over two decades. The purpose of this paper is to present a fuzzy quality function deployment (FQFD) model to identify customer requirements and design the production process and improve the quality of the T-shirts according to the requirements. To overcome the shortcomings of the traditional QFD, fuzzy set theory is integrated with HOQ. It will capture the vagueness of the customer requirements and facilitate to prioritise QFD information. For building HOQ, the design process starts with the data collection and ends with making some suggestions for improvement. Factors which improve the quality of the T-shirts have been identified from the HOQ matrices to develop some suggestions for improvements. The proposed improvements include: development of standard production operation of T-shirts, training workers, implementation of quality management department and development of flexible production schedule.

Keywords: ready-made garment; RMG; quality function deployment; QFD; fuzzy; house of quality; HOQ; quality improvement.

Reference to this paper should be made as follows: Kapuria, T.K. and Rahman, M. (xxxx) 'Quality improvement of T-shirt using fuzzy QFD: a case study', *Int. J. Management Concepts and Philosophy*, Vol. X, No. Y, pp.xxx–xxx.

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1 Introduction

The ready-made garment (RMG) industry is one of the leading boons in Bangladesh economy. RMG industry started in the late 1970s and within a short time period became a leading industry amongst all types of Bangladeshi industries. According to the Bangladesh Garment Manufacturers and Exporters Association (BGMEA), in the fiscal year 2015–2016, the Bangladesh RMG industry earned $28,094.16 million. A huge 82.01% export earnings come from an RMG sector from the total export earnings for Bangladesh. The most buyer countries are the USA and EU countries. In the present scenario of the Bangladesh export-oriented sector, Bangladesh garment industry is one of the most successful export oriented industry from over two decades. Now, Bangladesh is the second largest exporter of clothing in the world. In 2016–2017, total market size of the Bangladesh garment industry was $28,149.84 million. Remarkably, Bangladeshi garment manufacturers, export garments for the country specific and worldwide famous brands.

As a garment product, Bangladesh basically exports woven and knit products such as woven shirts, pants, knit shirts, polo shirts, jackets, trouser etc. Amongst them knit shirts are the most demandable item in the market. It is one of the most popular garments products that Bangladesh makes and exports. Companies like Jack & Jones, Primark, Walmart depends on Bangladesh-made T-shirts. They give subcontracts to Bangladeshi manufacturers to make T-shirts on behalf of them. But the current situation is worse for some quality issues. Buyers are not getting 100% high quality T-shirts. The current scenario of quality problems can be predicted from Table 1. Table 1 shows the number of defects and the rate of non-compliance.

Table 1 The number of defects and the rate of non-compliance tolerated by companies

Company	*Number of defective T-shirts (monthly)*	*Number of total T-shirts (monthly)*	*Rate of non-compliance (%)*
Ha-meem Group	6,003	35,000	17.16
Beximco Fashions Ltd.	3,856	32,022	12.05
Square Fashions Ltd.	2,678	25,250	10.61
Opex Sinha Group	4,315	30,000	14.39
Fakir Group	5,241	40,000	13.1%

Source: Respected company portfolio

It is happening mostly because of low skilled worker and lack of high quality inspection for the garments. And then defects still exist in the garments. As a result, at the time of the buyer's inspection, many lots are being rejected. So, the Bangladeshi manufacturers are facing financial issues. If the buyers are not able to find low quality T-shirts from the lots, they are accepting the delivery. But, when the T-shirt is reaching to the customers, if they find the quality problem, they are not buying the products. Consequently, shops are not being able to sell the products and they are sending back the products to the company.

Naturally, global economic and purchasing condition is changing in a rapid motion. These days, the garment industry is more focused on profit margin, customer perceived high quality products and productivity improvement. In garment manufacturing, lots of rejected garments are as usual to see after shipment. These non-repairable quality problems occur due to the use of low quality raw materials, problematic process, low skilled manpower or without the close supervision of production manager. Truthfully, every company wants to use high quality raw materials such as high-quality fabric. But fabric defect is a continuous problem in the manufacturing of garments. Yarn manufacturing equipment, knitting and weaving machines are continuously improving to produce defect free fabric. But it is not possible to manufacture defect free fabric. In the current situation, 'zero defects' is the goal of many fabric manufacturers. But it remains a goal and not a completed task. Many company conducts 100% inspection of incoming garments. They mark or label the detected defects and remove the fabric from spreading. At many times, many garments manufacturers depend on sewing operators to find out the defective cut parts and to replace the parts. Still, other apparel manufacturers are not attempting to find fabric defects. They are relying on final garment inspection to find out and remove the defect containing in the garments. To cope with fabric defects, all the methods to find out the fabric defect are costly and time consuming. A company utilises extra manpower to identify defects from fabrics. In addition, companies which are using semi-automatic machines to identify defects, it is also costly for them because of consuming electricity with manpower. In this case, fully automatic machine can solve the problem. Lots of a skilled operator and high quality automated machines are required to get 100% inspected fabric. Therefore, fabric defects are a major point of conflict to produce high quality garments. Due to highly competitive market, many garment manufacturers have started to look for different method and practices to reduce the defect percent rate. In short, when a company will be able to reduce defect rate, they would be able to produce high quality garments.

Currently to overcome this situation and meet the growing demand of high quality T-shirts, Bangladeshi garments manufacturers are stepping forward and investigating the quality problem deeply. Also, they are not restricted on findings, they are trying to solve the quality problem of the T-shirts. Because, they want to give the high-quality T-shirt for their loyal customers. Also, it is a pressing need for Bangladeshi garment manufacturers to overcome this situation to maintain the good reputation worldwide for the T-shirts. Every company wants to satisfy their customer fully. So, for getting high customer satisfaction, they need to produce high quality T-shirts.

Kapuria and Karmaker (2018) improved the quality of jute yarn using AHP-based QFD. They used AHP method to determine the weight of the criteria. Later, they used those weight in QFD method to prioritise the design requirements. Tahiduzzaman et al. (2018) used 5s and PDCA to improve the product quality of apparel industry in Bangladesh. Their contribution helped Bangladeshi companies a lot to improve the quality of the apparel product. Kapuria et al. (2017) used kaizen implementation technique to improve the quality of the apparel product. Its ultimate goal was productivity improvement.

Abdolshah and Moradi (2013) improved customer satisfaction by using the QFD approach in the service quality analysis. Specially, they applied the QFD methodology and mathematical optimisation to improve the Tehran's municipality service. As a result, their proposed method reduced the gap between municipal managers and citizens. The results also showed that QFD was a very effective tool for them to enable municipal managers to find out the demands of the citizens and to engage with engineering and technical requirements. Jin et al. (2014) investigated on how to prioritise engineering characteristics based on customer online reviews. He has taken many online reviews to acquire valuable customer requirements. They used an integer linear programming model to convert the pair wise results into original customer satisfaction ratings. They also got customer opinion concerning about engineering characteristics. Finally, they revealed the merits of the proposed approach. John et al. (2014) used awareness and effectiveness of quality function deployment (QFD) in design and build projects in Nigeria. Basically, they had applied the QFD function in the construction industry in developing countries (Nigeria). Developing countries such as Nigeria have not been practically aware about the benefits of QFD. Simply, they investigated the awareness and effectiveness of QFD, which increases the satisfaction of the customer in terms of quality, cost and project delivery time in design and build projects. Cerit et al. (2014) applied QFD model on a smartphone design. They explored the application of the QFD method on a new product (smartphone) development according to customer satisfaction. It was for Turkey's leading mobile communication operator to design a smartphone. Here QFD was used to guarantee the quality of the product or service. They also used the Kano model during the grouping and prioritisation of the customer necessities. Muda et al. (2015) used QFD model approach to determine the employer's selection criteria. They determined the most preferred criteria for selecting students for the industrial training, placement by using QFD model by obtaining feedback from the employers out there. They found from the study that communication skills and student participation in sports and communication activities in the university are the most desired selection criteria. They used a QFD approach to translate employer's feedback in improving the marketability of the students in the industry. Ionica and Leba (2015) integrated QFD model in the new product development (NPD) cycle. They proposed a methodology to evaluate the voice of the customers to design innovative products. They applied this method on a biometric identification system for emergency cases. They followed general QFD steps to develop a mathematical model which was quantified by an overall index. Kato et al. (2015) stated that "because of rapid growing of information and communication technology, high functionality is not the only one, flexibility is also essential to collaborate with the other." They used the MQFD model which means multispace QFD. Their M-QFD model helps the designer to extract the design elements based on diverse requirements such as customer requirements, company and society requirements, etc. Francis (2016) presented an engineering approach with QFD for an accreditation board of engineering and technology INC. He believed that the success of a QFD analysis is largely based on the quality of the voice of the customer, more specifically the customer requirements and their importance ratings. He applied QFD on a major course of the mechanical engineering program, where he considered course learning outcomes (WHAT's) and student outcomes issued by ABET as a technical requirement (HOW). The main objective of that paper was to pave a clear road to the faculty members and the engineering institutions to fully satisfy the ABET requirements. Buttigieg et al. (2016) combined QFD and logical framework approach to improve quality of emergency care in Malta. They used QFD to identify and analyse issues and challenges of the accident and emergency (A&E) department. In this case, logic framework approach helps to develop detailed project plans for quality improvement. The main purpose of combined QFD-LFA is to improve the process and system performance substantially. Kelesbayev et al. (2016) performed a case study on the universities. He used the QFD method as a quality improvement tool. According to their study, QFD method was utilised to identify whether an education service is pointed out by the student's need and expectations or not.

They also gave some policy to be followed by the universities. Overall, he tried to reveal the quality of the education service. Kunecka (2016) stated that, QFD method enables the rational design of the service. It is not only considered from technical perspective view, but also due to market and customer demands. House of quality (HOQ) is represented as a medium of transfer of customer expectations. He used QFD model prepared by 'Bartoz Solinski' in his paper "development of the quality of education for the nursing practice." In this paper he used QFD at different stages of the quality management process to improve the quality of practical training of future nurses. Kassela et al. (2017) applied QFD model in a housing association located in the United Kingdom (UK). By applying QFD here, they improved a company's performance. They successfully adapted, applied and utilised QFD tools within the challenging environment of social housing and other sectors. The final result had a positive impact upon a company for developing evidence-based strategy of operational change, control and improvement. Camgöz-Akdağ et al. (2016) employed QFD method for translating internal customer needs and expectations into appropriate service specifications for increasing internal customer satisfaction. He integrated SERVQUAL into QFD to set the success factors to improve quality in the textile industry. He defined that QFD application suggests him that internal customer focus has the highest weight score from the overall improvement. In short, QFD techniques help companies in better understanding the internal customer expectations. Some researchers applied QFD to the management of automation projects. The main contribution of this paper was a new matrix to help and support the project manager to plan requirement verification over project phases, by using team skills based on customer requirements. They proposed prioritising QFD to identify a set of requirements for each project phase, which are crucial to project success. Li and Song (2016) used rough VIKOR-based QFD model for prioritising design attributes of product related services. Bulut et al. (2018) investigated multi agent service quality problems in airport management. They used the QFD model to compromise the requirements of both airlines and passengers to ensure the quality implementations. Here, the multidimensional QFD model is used which can analyse the requirements of all agents despite the traditional QFD model to get appropriate solutions. Abuzid (2017) used QFD tools for quality improvements in curriculum design and teaching strategies to meet the customer needs. He applied QFD methodology to a university course in accounting. He made the university program more competitive by using QFD method. It helps him to define the real customer requirements. Here, QFD allows him to identify the learning needs of students in an accounting course and then students need translated into educational strategies which satisfy customer needs. The results allowed him to define "the right things to do for the first time." The first step is to do QFD precisely is to determine customer expectations rightly. It is crucial to satisfy customer needs. This paper demonstrates, how T-shirts quality problem can be identified and improved by using fuzzy quality function deployment (FQFD) method. Here, fuzzy set theory is integrated with HOQ to identify undefined customer requirements and to prioritise design requirements for final quality improvement of the T-shirts. In short, high priority design requirements will increase customer satisfaction significantly.

2 Literature review

Many times, many scholars worked on a fuzzy QFD method. According to Cohen (1995), Curcic and Milunovic (2007) and Prasad et al. (2010), customer requirements information can be used to calculate the importance of engineering characteristics. Khoo and Ho (1996), made fuzzy QFD more reasonable with fuzzified linguistic variables. Another specialist Chan et al. (1999), proposed fuzzy number and entropy methods as an important customer requirement. Wang (1999) viewed QFD as a solution of MCDM problem and proposed a new fuzzy outranking method.

Shen et al. (2001) viewed it necessary to translate customer requirements into trends for future analysis. Also, they mentioned that engineering characteristic's may be affected by several factors. Friman et al. (2001) and Higgs et al. (2005) discussed that the marketing researchers have identified the importance of service quality defined as customer satisfaction. The synthetic particle board was developed using QFD by Hergeth (2001). Many industries from all over the world are implementing QFD method successfully. Although, companies which use traditional methodology are now using the QFD methodology to overcome certain shortcomings.

According to Enriquez et al. (2004), customer requirements prioritisation is a very difficult task and QFD can be used to achieve prioritised needs. For overcoming the shortcomings of the traditional QFD, many specialists have applied FQFD model. Haider (2007) stated nearly 100% of the industry, which export garments supply to the domestic garment industry. Fonseca et al. (2010), described that only effective service quality can further improve corporate profit and effectiveness. Thus, how to improve T-shirts quality to increase customer satisfaction is an important issue in the Bangladesh. Chen and Ko (2008) presented fuzzy linear programming by using QFD method. Also, fuzzy normal relation evaluations method was shown for developing a new product. They used fuzzy linear programming method to identify higher level of engineering characteristics and design requirements to maximise customer satisfaction. They did it with respect to manufacturing company's resources, technical difficulties and fierce market competition limitation.

Wassermann's equation was used to identify the relationship between customer requirements and design requirements. They also presented that minimum promised level of each design requirement was known and promised level of design requirements could not be less.

Baba et al. (2009) defined QFD as a total quality management (TQM) tool that can be used to translate customer requirements into service requirements. HOQ process starts with customer requirements and customer needs identification by using customer survey. Then the customer requirements are converted into engineering characteristics. In this step, product design and development team can easily determine the relationship matrix between customer requirements and design requirements.

Manikandan et al. (2009) used QFD for designing an economic sampling plan for garments sector. Zhu et al. (2010), studied with respect to quality and satisfaction that operation is the internal side and customer is the external side of the service process. Kabir and Hasin (2011), expressed Bangladeshi local manufacturer needs to step forward to meet the growing demand of synthetic yarn.

Saleh and Sweis (2017) conducted soft and hard TQM practices and operational performance in Jordan manufacturing organisations. They conducted this study to eliminate the constraints of mixed results. Raut et al. (2017) used MCDM technique to warehouse location selection problem. They improved the quality of location selection problem. Dasgupta (2016) identified the problem in current competitive scenarios where companies can no longer compete by just focusing on providing superior value through their core products and practiced and created memorable customer experiences by providing a combination of products and services. Valaei et al. (2016) improved the overall service quality in courier service industry and the moderating impact of age, gender and ethnicity. Some researchers used multi-objective decision-making framework for preference selection index for assembly job shop scheduling problem. Razmi et al. (2016) designed organisational process maturity model for a gas refinery. They used MCDM and BPR concepts to improve the design quality of the process.

3 Background of the study

The purpose of this paper is to improve the quality of the T-shirts. Because, in Bangladesh, local garment manufacturers are routinely facing quality problems of the T-shirts. They want to give the highest quality T-shirts to their buyer for achieving higher customer satisfaction. We also know that customer requirements are changing day by day. Different customers have different expectations for their satisfaction level. With respect to customer needs, manufacturers want to give their best. By doing this properly, garments authority will not be able to cope with the fierce global competition. So, they are looking for the best solution for their quality problem. To overcome this situation, this research study will help them to identify the problem and also achieve final improvements.

4 Methodology

To improve the quality of T-shirts, we used FQFD model. FQFD stands for FQFD. FQFD model is very suitable to use to improve the quality. To fulfil the customer expectations, a systematic path of FQFD model is proposed. Here, fuzzy set theory helps us to understand the importance of the criteria and design requirements. And, QFD structured method helps us to prioritise the design requirements.

In QFD, quality is a pillar of customer satisfaction comparing with a product or service. QFD is a step by step method that uses management and planning tools to sort out and prioritise customer's needs quickly and effectively. QFD begins with an initial matrix which is defined in the HOQ. Primarily, QFD model focuses on the most important product or service criteria or qualities. After prioritising the criteria and qualities, QFD deploys them to the right organisation function for proper action. Necessary functions of an organisation which are customer driven qualities can be created with QFD system. Many QFD researchers told that QFD helps them to reduce product and service development cycle times by as much a nearly 80% with impressive improvements in terms of customer satisfaction.

The proposed QFD model helps to find out the best customer needs, to establish engineering characteristics, to make relation between customer needs and design requirements and prioritising design requirements.

The FQFD model paths are listed below. Figure 3 shows the methodology.

Step 1 Identify customer needs and obtain the ratings with the help of fuzzy.

Step 2 Calculate the weight and converting importance into weight.

Step 3 Establish design requirements.

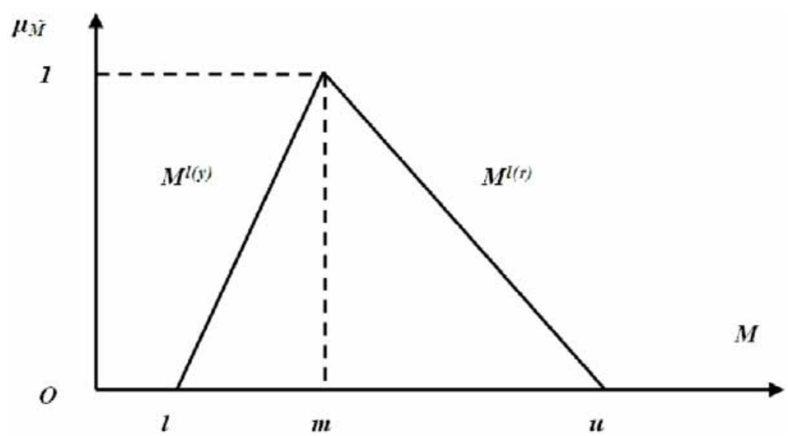
Step 4 Build QFD matrix.

Step 5 Prioritise design requirements.

4.1 Fuzzy set theory

Fuzzy set theory was introduced by Zadeh (1965a, 1965b). It was presented as an extension of the classical notion to set. In mathematics, fuzzy sets are sets and have a degree of membership. In decision making problem, fuzzy set theory deals with indistinct and unpredictable members to intensify precision. Thus, the vague data may be represented using fuzzy numbers, which can be further subjected to mathematical operation in fuzzy domain. This fuzzy number can be represented by its membership grade ranging between 0 and 1. Figure 1 shows triangular fuzzy number *M*.

Figure 1 Triangular fuzzy number *M*



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

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

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

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

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

The fuzzy summation ⊕ and fuzzy subtraction Θ of any two triangular fuzzy numbers is also TFNs, but the multiplication ⊗ of any two TFNs is only approximate TFNs. The data can be assessed using: if $\tilde{M}=(a1,b1,c1)$ and $\tilde{M}=(a2,b2,c2)$ are two TFNs, then their operational laws can be expressed as follows:

$$\tilde{M}_1\oplus\tilde{M}_2=a1+a2,b1+b2,c1+c2 \tag{3}$$

$$\tilde{M}_1\Theta\tilde{M}_2==a1-a2,b1-b2,c1-c2 \tag{4}$$

$$\tilde{M}_1\otimes\tilde{M}_2=a1a2,b1b2,c1c2 \tag{5}$$

$$\lambda\otimes\tilde{M}_1=\lambda a1,\lambda b1,\lambda c1 \text{ where } \lambda>0,\lambda\in R \tag{6}$$

$$\tilde{M}_1^{-1}=\left(1/c1,\ 1/b1,1/a1,\ \right) \tag{7}$$

4.2 QFD matrix

QFD matrix first originated in Japan. It is one of the most successful quality improvement tools. QFD deals with customer requirements and engineering characteristics. Also, QFD makes the best relationship between customer requirements and engineering characteristics. In short, QFD is an approach that adds the 'voice of the customers' into product design and development process. QFD has two parts. First one is voice of customers and second one is HOQ. Figure 2 shows the components of HOQ.

As an observation of the HOQ (Figure 2), the 'WHAT' room identifies the voice of the customers which is located at the left side of the matrix. Basically, 'WHAT' room answers the questions: "what requirements should be satisfied or are there any special features which the customer would be delighted to discover?" The 'HOW' room indicates the voice of the engineers or designers. For 'HOW' room each 'WHAT' items must be refined into 'HOWS'. But they must have to be actionable, quantifiable or measurable. The 'HOW' room located under the 'correlation matrix'. It answers the question: "how can these customer requirements be met in terms of design requirements."

The 'relationship matrix' – it makes the linkage between the engineering design requirements and voice of the customer and simply describes how 'HOWS' satisfy 'WHATS'. It uses a symbolic notation for representing weak, medium and strong relationship. In general, a strong connection between the two indicated by a circle within a circle (Θ), moderate connection indicated by a single circle (o) and weak connection represented by a triangle (Δ). The 'how much' room answers a common design question: "how much is good enough to satisfy the customer?" It is in the box beneath the relationship matrix. It provides designers with specific technical guidance.

Figure 2 Components of HOQ

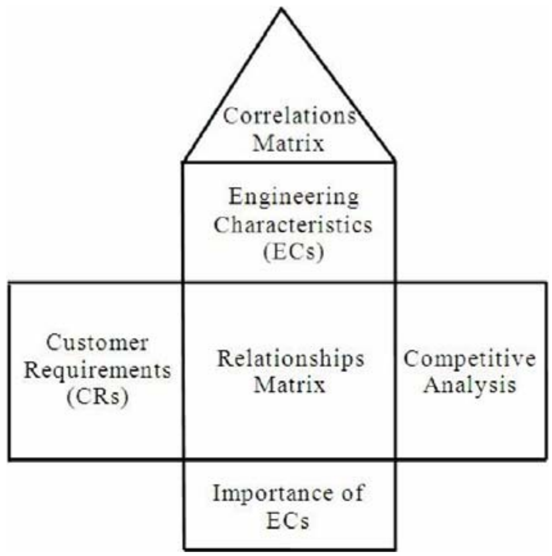
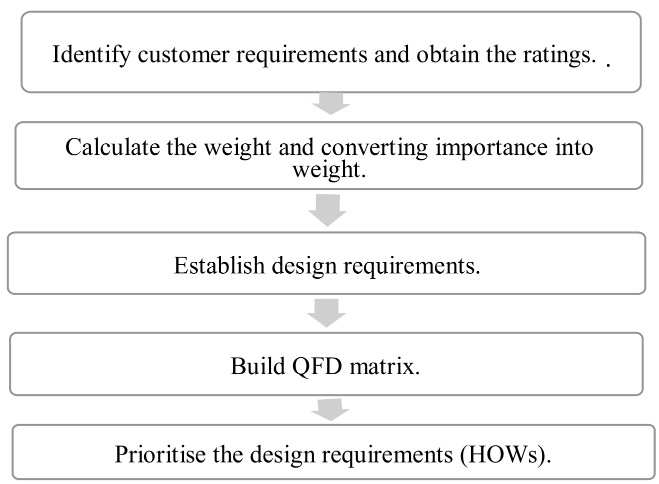


Figure 3 Methodology



The 'correlation matrix' roof find out how 'HOWS' items support or conflict with one another. It finds trade-off for negative items by adjusting 'how much' values. Here, tradeoffs must be resolved, or customer requirements would not be fully satisfied. The 'engineering competitive assessment' room collects the data in engineering terms and records it on the chart. An importance rating is provided based on a certain scale. The 'marketing competitive assessment room' is located next to the 'relationship matrix' room. It is also called the 'customer competitive assessment' room. A weighted scale is also used here.

5 An illustrative example

In this section, Bangladesh's top 5 export-oriented garments (Ha-meem Group, Beximco Fashions Ltd., Square Fashions Ltd., Opex Sinha Group and Fakir Group) are used to implement the proposed FQFD model. These top 5 companies are currently working on raising customer satisfaction and quality improvement of the T-shirts.

5.1 Identifying customer needs

For identifying customer needs, we have developed total 27 questions and experts in this field reviewed and finalised 13 questions for the survey. We have interviewed total 99 people from those companies including factory workers, Industrial engineers, floor supervisors, production managers, merchandiser on behalf of the buyers. Table 9 shows the percentages on the profiles of the interviewees.

A rating scale from 0 to 80 was used to understand the necessity of the needs. Table 2 shows the combined translated customer need and rating in percent.

Table 2 Summary of combined customer demand

No.	*Combined customer demand*	*Average rating (percent)*
1	No broken stitch	80
2	No skip stitch	78
3	No open seam	75
4	High quality fabric	72
5	Proper printing	70
6	No spot on the garments	65
7	No hole	63
8	No part shading piece	58
9	Properly attached button	55
10	Unwanted thread trimming properly	50
11	Option to change	46
12	Reasonable cost	30
13	Continuous market supply	20

5.2 Simple weight calculation and importance of fuzzy scale converting

After obtaining customer requirements and ratings, multiple regressions are used to get the level of importance of customer expectations. Then weight is calculated according to ratings. Here, fuzzy linguistic terms are used to assign the importance of customer needs. Triangular fuzzy numbers are used to help the design team to eliminate indistinct of fuzzy linguistic terms. Figure 4 shows fuzzy triangular membership functions for weights of the customer requirements, Table 3 shows linguistic variable and the fuzzy scale for describing the weight of the criteria and Table 4 shows the weights for the different customer. Table 5 shows the importance converted into fuzzy scale.

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

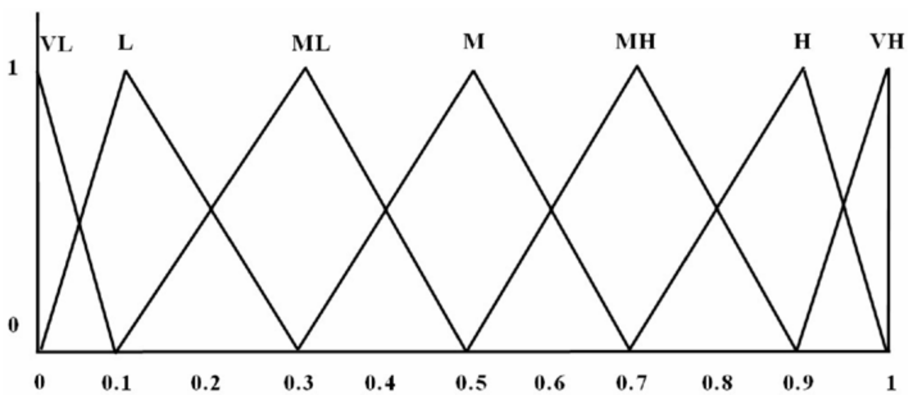


Table 3 Linguistic variable and the fuzzy scale for describing weight of the criteria

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 4 Weight of the customer demand

No.	*Combined customer demand*	*Average rating (percent)*	*Weight (percent)*
1	No broken stitch	80	80
2	No skip stitch	78	78
3	No open seam	75	75
4	High quality fabric	72	72
5	Proper printing	70	70
6	No spot on the garments.	65	65
7	No hole	63	63
8	No part shading piece	58	58
9	Properly attached button	55	55
10	Unwanted thread trimming properly	50	50
11	Option to change	46	46
12	Reasonable cost	30	30
13	Continuous market supply	20	20

Table 5 Importance converted into fuzzy scale

No.	*Combined customer demand*	*Weight (percent)*	*Importance*	*Fuzzy scale*
1	No broken stitch	80	1	VH
2	No skip stitch	78	0.97	VH
3	No open seam	75	0.93	VH
4	High quality fabric	72	0.90	H
5	Proper printing	70	0.87	H
6	No spot on the garments.	65	0.81	H
7	No hole	63	0.78	MH
8	No part shading piece	58	0.72	MH
9	Properly attached button	55	0.68	MH
10	Unwanted thread trimming properly	50	0.62	MH
11	Option to change	46	0.57	M
12	Reasonable cost	30	0.37	ML
13	Continuous market supply	20	0.25	ML

5.3 Establishing design requirements

Establishing design requirements is the most critical and time devour matter. In this section, experience and expertise are needed to build a strong design requirement to meet the customer demand. Table 6 shows the design requirements with respect to customer needs.

Table 6 Design requirements based on customer needs

No.	*Customer needs (whats)*	*Design requirements (hows)*
1	No broken stitch	Convincing thread
		Appropriate thread tension
2	No skip stitch	High attention of worker
		Right needle size
3	No open seam	Proper seaming
		Closed supervision by production manager
4	High quality fabric	Proper fabric inspection
5	Proper printing	Providing best printing machine
6	No spot on the garments	Attentive worker
		Clean work area
7	No hole	Proper fabric inspection
8	No part shading piece	Very carefully matching parts
9	Properly attached button	Using best button attaching machine
10	Unwanted thread trimming properly	Operator efficiency
		Proper trimming and finishing
11	Option to change	Create mutual understanding environment
12	Reasonable cost	Resource optimisation
13	Continuous market supply	Proper utility support
		Time to time communication to customer

Figure 5 Fuzzy triangular membership functions for interrelationship matrix

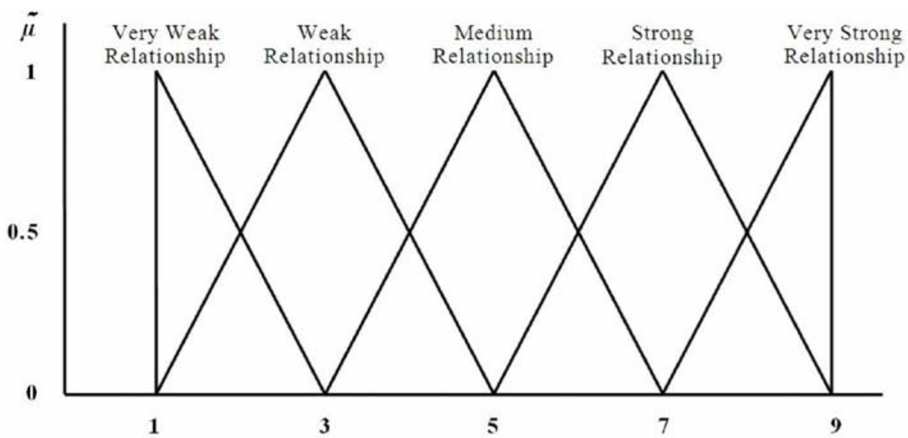


Figure 6 The QFD matrix

What's ↓ / *How's*	*Importance*	*Convincing thread*	*Appropriate thread tension*	*Attention of worker*	*Right needle size*	*Proper seaming*	*Closed supervision*	*Proper fabric inspection*	*Best printing m/c*	*Clean work area*	*Matching carefully*	*Best attaching m/c*	*Operator efficiency*	*Trimming and finishing*	*Mutual understanding*	*Optimisation resource*	*Communication*
No broken stitch	VH	VS	VS		S		M										
No skip stitch	VH			VS	S		M										
No open seam	VH			VS	S	VS											
High quality fabric	H						S	VS									
Proper printing	H						VS		VS			VS					
No spot on the garments	H			VW						S							
No hole	MH						S	VS									
No part shading piece	MH			M			VS				VS		VW				
Properly attached button	MH			M								S	W				
Unwanted thread trimming properly	MH			VS			S					VS	M	S			
Option to change	M														S		M
Reasonable cost	ML						M						W			S	W
Continuous market supply	ML						M									M	VS
Target value		9	9	30.49	20.30	8.37	37.49	15.12	7.83	5.67	6.48	18.17	6.97	4.34	3.99	3.84	6.21

5.4 Building QFD matrix

In this step, we will build relationship for customer requirements with design requirements to meet the highest possible satisfaction. Experts are also taken as a part of this to get the best relationship to customer needs with respect to design requirements. Figure 5 shows the fuzzy triangular membership functions for interrelationship matrix.

Table 7 shows the linguistic variables and fuzzy scale for interrelationship matrix and Figure 6 shows the QFD matrix.

Table 7 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)	1	$\mu M(x) = (3–x)/(3–1)$	$1 \le x \le 3$	(1, 1, 3)
Weak relationship (W)	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)	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)	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)	9	$\mu M(x) = (x–7)/(9–7)$	$7 \le x \le 9$	(7, 9, 9)

6 Results and discussion

The reason behind applying FQFD model is to find the best design requirements which will fulfil customer requirements. In this paper, the best design requirements have identified using FQFD model and design requirements are prioritised from largest to smallest.

From Table 8, we can analyse the prioritised design requirements. Closed supervision by production manager has the highest target value and weight percentage of 37.49 and 19.40. Proper fabric inspection has the target value and weight percentage of 15.12 and 7.38.

To implement these QFD results, production managers need to play a key role to solve the problem precisely by following these design requirements. High attention of worker has the target value and weight percent of 30.49 and 15.78. So, highly skilled worker can play a game changing role here. Maintenance personnel needs to be responsible and careful at the time of the machine maintenance. A simple fault in the machine makes the operator responsible for the problems. Best button attaching machines have the target value and weight percent of 18.17 and 9.41. Factory owner needs to pay lots of attention on buying best button attaching machine. Operators also need to be aware about their machines which have 6.97 target value and 3.61 weight percent.

Right needle size has the target value and weight percentage of 20.30 and 10.51. The workers need to check their needle size for the specific job and to maintain cleaning code of conduct for their dress and hand.

Table 8 Weighted design requirements

No.	*Design requirements (how's)*	*Target value*	*Weight percent*
1	Closed supervision by production manager	37.49	19.40
2	High attention of worker	30.49	15.78
3	Right needle size	20.30	10.51
4	Using best button attaching machine	18.17	9.41
5	Proper fabric inspection	15.12	7.83
6	Convincing thread	9	4.66
7	Appropriate thread tension	9	4.66
8	Proper seaming	8.37	4.34
9	Providing best printing machine	7.83	4.06
10	Operator efficiency	6.97	3.61
11	Carefully matching	6.48	3.36
12	Time to time communication to customer	6.21	3.22
13	Clean work area	5.67	2.94
14	Proper trimming and finishing	4.34	2.25
15	Create mutual understanding environment	3.99	2.07
16	Resource optimisation	3.84	1.99

Proper seaming has the target value and weight percentage of 8.37 and 4.34. Garment workers need to be attentive when seaming a garment. Improper seaming can lose parts of the garments.

Time to time communication to customer has the target value 6.21 and 3.22 prioritised weight percent. Time to time communication with the customer also plays a vital role to generate and gather customer data for further improvement.

Table 8 shows the weighted design requirements. And this prioritised design requirements would be help the companies to choose the best design option for them. Ultimately, it is improving the quality of the shirt and raising customer satisfaction.

7 Limitations and recommendation

There are some limitations of this study. We have only considered top five garment manufacturers to improve the quality of T-shirts. If we would take lower ranked garment manufacturers, then we had lots of possibilities to get more quality problems. Also, every company wants skilled and properly trained workers. Sometimes they are unable to find proper skilled workers. Also, every company will not be able to maintain the cleaning code of conduct.

In the recommendation list, hand cleaning machine is recommended. Some company will not be willing to buy hand cleaning machines as it will increase the production budget.

To standardise the T-shirts production, we have listed some suggestions which will help those manufacturers produce high quality T-shirts. Table 10 also represents the investment cost for the m/c and training programs.

a The company can arrange a rigorous training program about lean management tool like 5s, poka-yoka, visual management system to create awareness of their workers to prevent mistakes. Also, Bangladesh Knitwear Manufacturers and Exporters Association (BKMEA) runs several rigorous lean manufacturing training programs for both industrial engineers and factory workers. Factory owners can take help from them to make the organisation better.

b Hand cleaning machine is mandatory for all the workers and staff members at the entrance of the factory. It will ensure no dirty spot on the T-shirts.

c Separating and maintaining floors and factory cleaning service strictly.

d Proper implementation of TQM department. They will find out the quality problems and ensure high quality continuously.

e Must need to run and maintain flexible production schedule.

f Factory workers must need to be motivated by production managers and industrial engineers to give the best results. They need to show the loyalty about their work. In this case, the company can share bonus and incentives for motivating themselves.

Table 9 The percentages on the profiles of the interviewees

Profiles	*Attended in the interview*	*Percentages on the profiles of the interviewees*
Factory workers	35	35.36
Industrial engineers	15	15.16
floor supervisors	22	22.23
production managers	18	18.19
Merchandiser	9	9.10

Table 10 Investment cost

Item	*Price*	*Quantity*	*Final result*
Hand cleaning m/c	$1,000	2	Enhanced productivity
Training program arrangement with little snacks	$200	One program in three months period	

8 Conclusions

Everyone wants to produce high quality products. It is always very difficult to create and implement high quality production techniques in an industry. High quality product means higher level of customer satisfaction. Quality improvement of a product has always been a difficult and challenging job. Because, a major fault can cause disaster for a company. When it comes down to improving the quality of a garments product, it becomes more challenging.

The unique contribution of this paper is to improve quality of T-shirt through FQFD model. In previous, there is no research available through FQFD model for the quality improvement of the T-shirt. That is why, this FQFD model makes this research outstanding.

From the theoretical implication view, FQFD model is presented for the quality improvement of the T-shirt. To eliminate the shortcomings of the traditional QFD, FQFD model is used for exact and accurate translation of the customer requirements into design requirements.

According to the result, closed supervision and high attention of worker are the top two quality problems which need to be minimised on the high priority basis. The other problems should also be minimised. Because, in garments a single problem can create a disaster for the company.

For enhancing closed supervision, production managers need to come forward. They need to pay more attention on the production line at the time of production. They need to follow the preventive quality assurance techniques. Such as they can analyse the production process for negative trends, if something left alone, could drift into a non-conformity. They can document such analysis results into a control plan. They can perform statistical process control technique through their production process. They can also implement lean thinking to eliminate waste.

Also, factory workers need to be attentive when they are in front of the machines. Rigorous training programs should be established to continuously improve worker skills. There are many lean manufacturing tools such as poka-yoka mistake proofing system, visual management system which help the workers to avoid any mistake. A company need to raise awareness among its workers about these systems through their training programs.

Some future research directions are suggested. From the limitations, we have only taken the top companies for the quality improvement. So, it is better to take all ranges of garments companies from top tier to low tier. Then, there will be more quality problems to be solved. Also, by using AHP-based QFD method, T-shirts quality can be improved. Finally, FQFD model allowed the Ha-meem Group, Beximco Fashions Ltd, Square Fashions Ltd, Opex Sinha Group, Fakir Group to reduce the quality problem and help to make good profit as well.

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