CUSTOMER DRIVEN QUALITY IMPROVEMENT OF A SPECIFIC PRODUCT THROUGH AHP AND ENTROPY-BASED QFD: A CASE STUDY

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ABSTRACT

Understanding the voice of the customers (VOCs) and properly incorporating their preferences and perceptions into the conceptual design process is the core step of customer-driven product development. To improve customer satisfaction and market profitability, the design team should have a customer-driven quality management and product development system. Quality function deployment (QFD) is an important customer-driven quality management tool that helps identify customer requirements and translate them into proper technical measures. This paper focuses on the application of the AHP and an entropy-based QFD approach on a manufacturing company to improve the quality of its product (blender) and determine the priorities for further improvement. The paper shows how customer requirements can be identified and applied to prioritize the design requirements for improving the quality of a blender. The Analytic Hierarchy Process (AHP) is integrated to determine the final importance of the weights of the customer needs, and entropy is used to determine the set of priority ratings. This integrated framework can help achieve an effective evaluation of the final design solution for product development by overcoming the pitfalls of the traditional QFD approach. An application in a Bangladeshi company that produces blenders is presented to illustrate the performance of the proposed approach.

Keywords: Integrated QFD; product development; customer satisfaction; AHP; entropy

1. Introduction

In today's global markets with the fierce competition and rapid changes in customer orientation, companies need to deliver products and services that are responsive to the customers' expectations in order to enhance corporate profit and competitiveness. To improve customer satisfaction, the design team should have a customer-driven quality management and product development system. Quality function deployment (QFD) is a structured total quality management tool which can translate customer requirements into specific technical or engineering characteristics. This customer-driven design and manufacturing approach originated in the late 1960s in Japan and is now widely used in all sectors such as banking, educational institutions and the garment industry. It helps the quality improvement team by identifying customer needs (performance needs) and converting them into design requirements. The proper use of QFD can help a company evaluate its design requirements, and as a result make the product more responsive to the customers. The conventional QFD methodology involves four sets of matrices called the house of quality (HOQ), namely product planning, part planning, process planning, and operations/production planning. With the help of these four matrices, the QFD translates customer requirements into engineering characteristics, and subsequently into parts characteristics, process plans, and production requirements. The customer requirement planning matrix is fundamentally and strategically important in the QFD system. It is the communication platform in the investigation of what customers want and their relative position in the market. The matrix starts with the identification of the "voice of the customer" (VOC) which is obtained from an interview with the customer, a market study and past data. Since customer needs vary, the relative importance of the WHATs is articulated by allowing the customers to state their perceptions on the relative importance of the WHATs. Then, a list of measurable engineering characteristics is specified and used to convert the customer requirements. Next, the product development team develops a relationship matrix between the customer requirements and the engineering characteristics, and performs the competitive analysis and the correlations between the engineering characteristics. Finally, the importance of the engineering characteristics is calculated using the information obtained from the house of quality (Cohen, 1995; Curcic & Milunovic, 2007; Durga Prasad et al., 2014). QFD is used to improve the components, to accelerate the improvement rate, and to determine the effects of the design changes. The customers' requirements and satisfaction should be considered the priority for every product design and specification. Therefore, QFD is an important and suitable tool for successful new product development. It is used in the early phase of a new or improved product/service design process and can support the process from problem identification to design specification. Since 2000, many researchers have applied QFD to present a new product or to improve a product design, and some of these uses are explained in Table 1.

Table 1
Examples of research on QFD

Authors/Developer	Research Nature	Remarks
Prasad (2000)	A concurrent function development procedure has been applied for a workgroup based engineering design process.	It alters QFD.
Herrmann et al. (2000)	Market-driven product & service design.	They tried to bridge the gap between quality improvement and customer requirements & satisfaction through QFD.
Harding et al. (2001)	Market-driven design system has been implemented and tested by helping the design team analyze and use the market information throughout the design process.	QFD is adopted to present and analyze the quality of the product.
Pullman et al. (2002)	Compare two product design approaches, QFD, and conjoint analysis.	QFD highlighted the importance of starting explicitly with customer requirements.
Kwong&Bai (2003)	QFD process was compared with the conventional AHP for a hair dryer design.	Improve the imprecise ranking of customer requirements.
Lai et al. (2004)	A combination of the Kano model & QFD is proposed to meet customer requirements.	A new way to optimize the product design.
Iranmaresh et al. (2005)	An integrated approach is presented to optimize product cost. It respects the customer perception of a product where the modified QFD method is used.	An illustrative example is given to demonstrate the use of the method.
Lin et al. (2006)	Explains a novel procedure to effectively link customer requirements with design characteristics for product design based on the concept of QFD.	The procedure is validated using a case study on the design of functional clothes.
Sakao (2007)	Proposes a general design methodology to effectively	The proposed methodology effectively supports the

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	support the environmentally consciousness design of products by using three tools; LCA, QFDE, and TRIZ.	wide range of product planning and conceptual design stages in the upper stream of eco-design.
Das & Mukherjee (2008)	Developed an AHP-QFD framework for designing a tourism product.	The design of a tourism product incorporating the diverse needs of tourists.
Zhai et al. (2009)	Proposes a rough set based QFD approach to managing the aforementioned imprecise design information in product development.	A case study on a bicycle design is used to illustrate the proposed approach and effectively manage the imprecise design information and facilitate decision-making in product development.
Felice & Petrillo (2010)	Proposed a new methodological approach to define customer specifications through the employment of an integrated QFD – AHP model.	The approach has been validated in a real case study about the filter in ceramic material production.
Liu (2011)	Integrates fuzzy QFD and the prototype product selection model to develop a product design and selection approach.	The proposed method provides product developers with more useful information and precise analysis results.
Sharma (2012)	Attempts to merge these diverse tools of customer-orientation, financial consideration, and value creation, thus integrating target costing and value engineering into QFD framework.	A case study has been discussed and issues of implementation of this cross-disciplinary approach from the perspective of an entrepreneur by selecting a consumer product are highlighted.
Bereketli & Genevois (2013)	Proposed a multi-aspect QFD for environment method to identify improvement strategies in eco-design.	The method applied for the product "hand blender", a member of electrical and electronic equipment family.
Vinodh et al. (2014)	Propose a model that integrates environmentally conscious QFD, the theory of inventive problem-solving, and AHP for innovative	The voice of the customer was captured and translated to engineering characteristics using

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	and sustainable product development of automotive components.	environmentally conscious QFD.
Muda and Roji (2015)	Propose a framework based on QFD approach for determining employer's selection criteria.	The authors tried to identify the gaps in the curriculum based on the requirements from the industry.
Onar et al. (2016)	Proposed a new fuzzy quality function deployment (QFD) approach to effectively determine the design requirements (DRs) of a computer workstation.	The proposed model is more efficient than the existing QFD.
Carpinetti et al. (2018)	Proposed a group decision model based on QFD and hesitant fuzzy to select metrics for supply chain sustainability management.	The model focuses on the selection and weighting of the metrics as a group decision process.
Yazdani et al. (2019)	Proposed a fuzzy MCDM framework having integration of QFD and grey analysis.	This model can facilitate decision making process.

During the complex decision process, determining the final importance rating of the customer requirements is a crucial step (Wang, 1999; Armacost et al., 1994; Chan et al., 2002; Kim et al., 2007). A proper estimation of the final importance ratings of the customer requirements helps the planning team design and develops appropriate design characteristics to match or exceed the customer satisfaction of all of the competitors in the target market, and therefore leads to more competitive advantages.

Generally, four steps are required to derive the final importance ratings of customer requirements in the house of quality model (Chan & Wu, 2005). The steps are as follows:

Step 1. Identify potential customers and acquire their requirements.
Step 2. Determine the fundamental importance ratings of each requirement.
Step 3. Identify competitors and conduct a competitive analysis to know the market position.
Step 4. Determine the final importance ratings of the customer requirements.

Since customer requirements are the crucial factor in the HOQ model, considerable effort should be taken to capture those requirements (Lu et al., 1994). In the literature, there are numerous methods available for collecting the voice of customers (VOCs), including personal interviews, warranty data, feedback, affinity diagrams, analyzing complaints, field reports and rough set, but all of the approaches have some pitfalls and are not capable of properly acquiring the customer requirements.

Various techniques exist to determine the fundamental importance ratings of the customer requirements. The point scoring scale and conjoint analysis method are the simplest methods that are used to calculate the relative importance of the customer requirements. Several researchers have focused on the use of the Analytic Hierarchy Process (AHP) to estimate the importance weights (Armacost et al., 1994; Lin et al., 2008; Li et al 2009; Vinodh et al., 2014). Hoet al. (1999) described a group decision-making approach in the quality function deployment model to estimate the weights of the customer requirements. A number of scholars have proposed the integration of the fuzzy set theory or integrated fuzzy set approaches into the house of quality to overcome the pitfalls of the traditional model. Different integrated fuzzy set approaches include triangular fuzzy numbers, fuzzy AHP, fuzzy arithmetic, and the fuzzy Analytic Network Process. Chen et al. (2006) rated the technical attributes in fuzzy QFD by integrating the fuzzy weighted average method and fuzzy expected value operator. Chan et al. (1999) combined triangular fuzzy numbers and entropy methods to determine the final importance of the customer requirements. Several researchers have developed fuzzy AHP based on the QFD model to prioritize customer requirements (Kabir & Hasin, 2011; Liu; 2011; Vanegas & Labib, 2001; Lin, 2003; Chan & Wu, 2005; Kahraman et al., 2006). Chan et al. (1999) used a fuzzy arithmetic approach to determine the importance of each requirement. The fuzzy Analytic Network Process was used by several researchers to determine the fundamental importance ratings (Tan & Shen, 2000).

Another important factor for determining the final importance of the customer requirements is the competitive priority ratings of a company that are obtained through the analysis of the company's relative positions. The traditional method used to determine this is the sales point concept. Currently, different methods are suggested to more objectively and convincingly analyze company performance ratings. Wang et al. (2015) suggested the entropy method to measure the competitive priority ratings of each customer requirement. Kano's model was incorporated into the competitive analysis in order to properly capture the voice of the customers (VOC) (Madzík, 2018).

From the discussion, it is quite obvious that an accurate determination of the customer requirements is very crucial to prioritize the design characteristics. An improper priority analysis of the customer requirements leads to an inappropriate decision-making product improvement and ultimately hurts customer satisfaction. After reviewing the literature, the authors think it is appropriate to integrate the Analytic Hierarchy Process (AHP) and the entropy methods to determine the final importance of the customer requirements.

This research aims to develop a framework to improve the quality of a product and find the priorities for further developments. To achieve this goal, AHP and entropy-based QFD are used. After the extraction of the customer requirements, the Kano model was used to understand the nature of these requirements. Then, AHP was used to assess the relative weight of each requirement. Entropy was applied to measure the competitive priority rating of each requirement. Finally, a HOQ matrix was developed to prioritize the design requirements through a quantitative analysis. From the customers' requirement

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identification to design characteristics, each step of this framework underwent a quantitative analysis to avoid the vagueness of the subjective judgment. Therefore, this integrated framework can result in a more realistic and promising decision than a stand-alone QFD. The proposed framework was applied to improve the quality of a renowned company in Bangladesh for the validation of the framework.

2. Research methodology

The basic conceptual structure coordinates the concepts of the Analytic Hierarchy Process (AHP) and the entropy method into the house of quality (HOQ) model to present an effective method for converting customer requirements into design requirements. The suggested approach begins by using the AHP method to calculate the rating of the relative importance of the customer needs. The entropy method is introduced to measure the companies' current and target performance in terms of WHATs to drive the final importance rating of the customer needs. Finally, the customer satisfaction management strategy, QFD, is applied to translate the customer desires into an actual technical requirement to satisfy the customer needs. A schematic diagram in Figure 1 shows the outline of the proposed methodology.

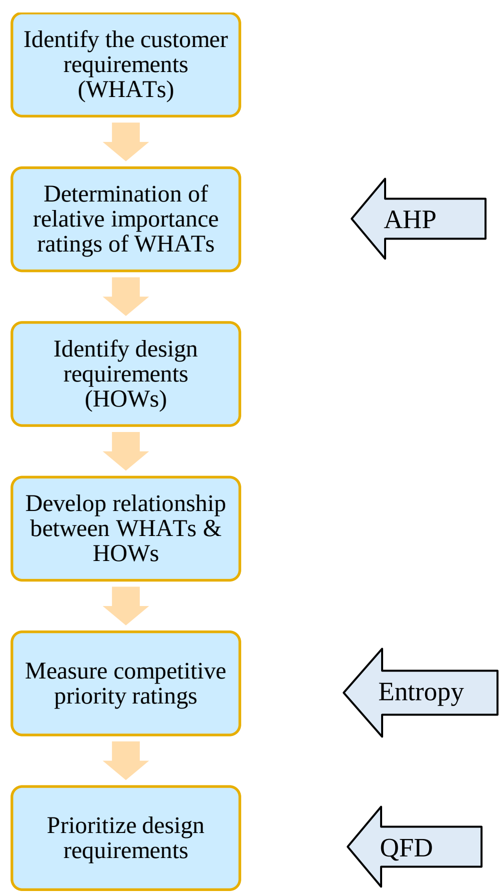

Figure 1 Outline of the proposed methodology

3. Description of a 7-step HOQ model

In this study, a 7-step HOQ model is proposed to identify customer needs and prioritize the technical measures to satisfy their needs. The elements of the HOQ are illustrated in Figure 2. A 7-step HOQ model can be described as follows:

Step 1. Identify the customer and their requirements (WHATs)

The first step in a QFD is to analyze the market segments during the process and identify who the ultimate customers are and what their needs are. The potential customer is the main focus when designing or modifying the product. The customer of the product should be concerned about the product and the company producing the product. Necessary data from customers were collected through interviews, questionnaires, and investigations. The only way to satisfy customers is through the realization of the customers' needs regarding a product.

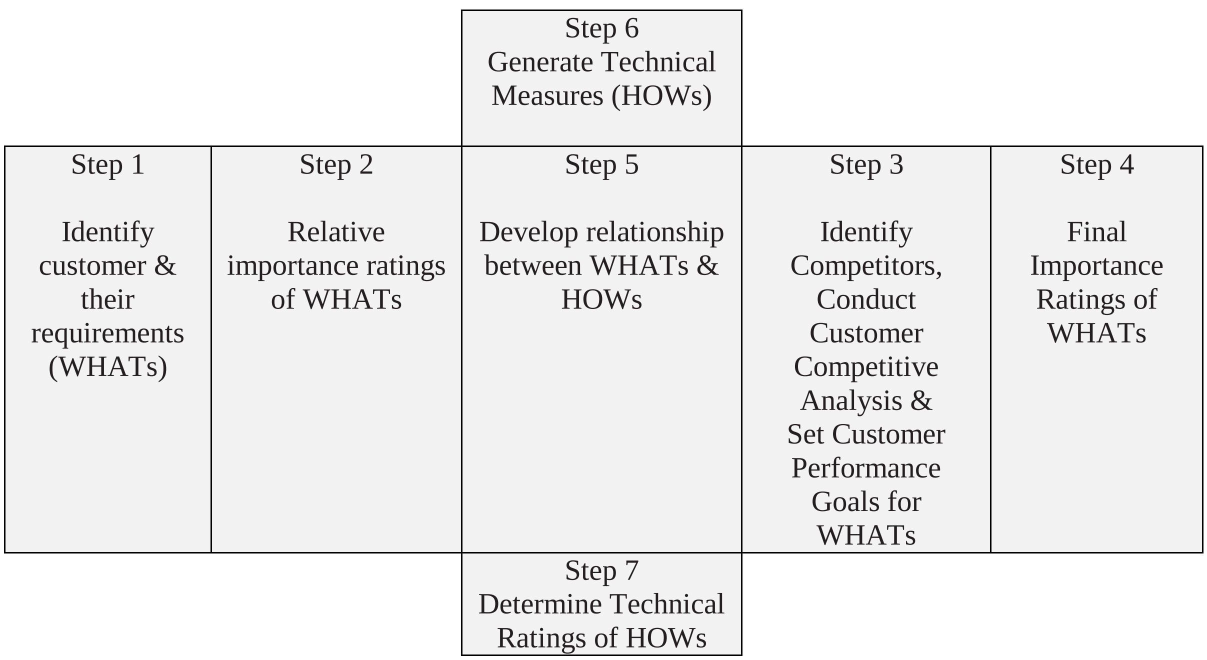

Figure 2 Elements of the house of quality (HOQ)

The presence of appropriate design characteristics can create more customer satisfaction if they are capable of fulfilling certain customer needs when they are made known before designing or manufacturing the product. Therefore, it is very important to capture all of the important customer requirements and integrate them into the product in the form of technical measures. This process is not easy because customers cannot always express all of their desired product attributes. It is essential to use some techniques to identify all of the relevant customer requirements. The Kano model is one effective technique for categorizing customer requirements. According to this model, there are three categories of customer requirements (Figure 3) which can influence user satisfaction.

These categories are:
1) Basic attributes (unsatisfied or must-have)
These meet the primary needs of the customers. The presence of these requirements does not expand the customers' satisfaction, but their exemption creates a high level of frustration. Customers see these attributes as prerequisites. For example, 'proper blending' is considered a minimum feature that customers naturally expect from a blender.

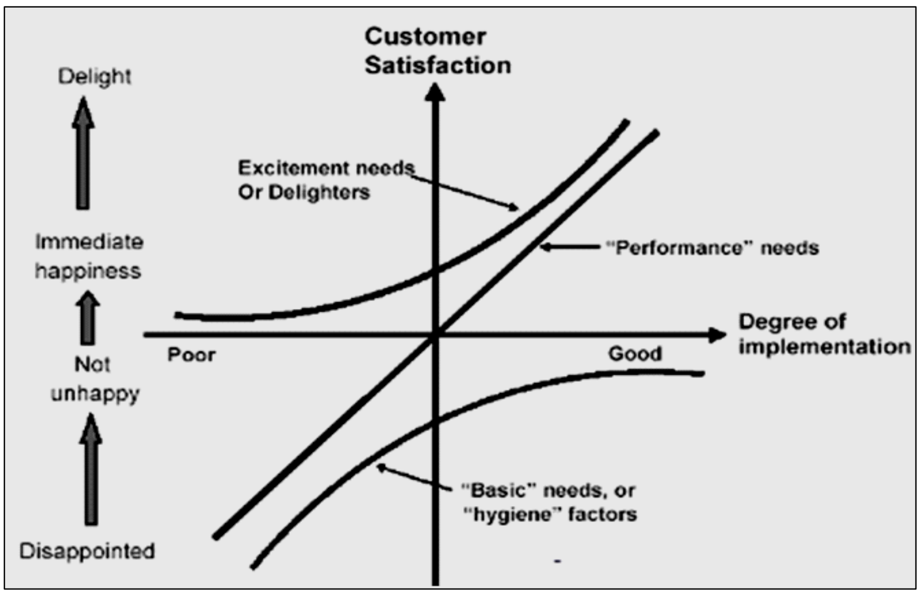

Figure 3 The Kano model

2) Performance requirements
The presence or absence of these attributes affects the customers. These attributes produce both satisfaction and dissatisfaction depending on the performance levels, and if they are present, the customer will be satisfied and vice versa. 'Less energy consumption' is one type of performance attribute.

3) Attractive or excitement requirements
These attributes are the key factors for improving customer satisfaction. When these are offered, customers become excited, but their absence does not cause dissatisfaction. High performance of these attributes has a positive impact on the overall satisfaction level. Providing a 'multiple operations' feature is considered an attractive need.

Step 2. Compute the fundamental importance of the customer requirements
The needs of the customer vary depending on the different degrees of importance, and companies focus on that particular requirement which is relatively more important than others. The relative importance of the customer requirements is articulated by allowing the customers to state their perceptions on the relative importance of the requirements. In

this research, AHP, one of the well-known multi-criteria decision making (MCDM) methods, has been used to obtain the customers' perceptions as well as to determine the importance weight of the customer requirements. Suppose the customers' requirements are represented by W_n (where n=7), and then a 7×7 comparison matrix is formed. The AHP method is applied to the matrix to derive the degree of the weight of each WHAT.

Step 3. Identify competitors and conduct a customer competitive analysis

The company needs to identify its competitors who produce similar products. To keep pace with competitors in a competitive business environment, a company needs to know the strengths and constraints of all aspects of a product with respect to its main competitors. This is done by having customers express their opinions and rate the relative performance of the company and its competitors for each customer requirement. There is an unending need for an aggregation of expert opinions that prevents bias and diminishes unfairness in the decision process. Therefore, a group decision should be adopted to improve the customer competitive priority ratings for the customer requirements in the evaluation process.

Step 4. Determine the final importance ratings of the customer requirement

The final importance ratings of customer requirements are calculated through the multiplication of the relative importance perceived by customers, the competitive priority and the improvement ratio obtained from step 3. Companies must give more attention to customer requirements with higher final ratings which indicate both higher importance and potential business benefits to the company.

$$Final\ importance\ ratings\ of\ customer\ requirement = Relative\ \text{importance} \times \text{Competitive priority rating} \times \text{Improvement ratio}$$

Step 5. Develop technical or engineering characteristics (HOWs)

After the customer requirements are identified, the next task is to generate a set of design requirements (HOWs) from the company's technicians or product development team to translate customer requirements into meaningful engineering characteristics.

Step 6. Develop the interrelationship matrix between WHATs and HOWs

The interrelationship matrix, an essential part of the house of quality (HOQ), is produced by analyzing to what extent the customer requirement is technically related and influenced by the engineering characteristics. The accuracy of the matrix depends on how carefully and collectively the relationship is developed.

Step 7. Determine the technical ratings of the engineering characteristics

The technical ratings of the design requirements are calculated by the multiplication of two factors, which are the final importance ratings of the customer ratings and the relationships between the engineering characteristics and the customer requirements.

$$Technical\ ratings\ of\ engineering\ characteristics = \text{Final importance ratings of customer requirements} \times \text{Interrelationsip matrix}$$

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The actual design ratings of the HOWs are determined by two factors, which are the final importance ratings of the WHATs and the relationship between the HOWs and the WHATs. This rating shows the basic importance of the HOWs progress in relation to the WHATs.

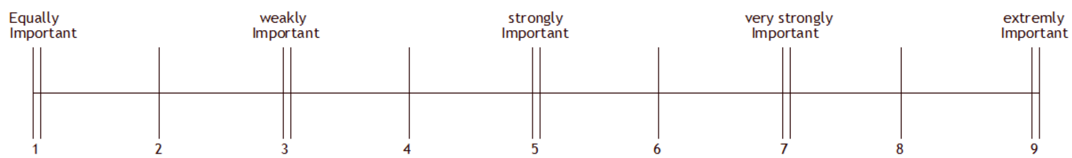
3.1 Proposed scales

Scale 1: To measure the relative importance of the WHATs: In this study, Saaty's fundamental scale for pair-wise comparison was used to measure the relative degree of each customer requirement (WHAT) (Saaty, 2005). Table 2 represents the fundamental scale used for pair-wise comparison.

Table 2
Fundamental scale of Saaty (Saaty, 2005)

Relative importance (a_{ij})	Description
1	Equal importance of i and j
3	Moderate importance of i over j
5	Strong importance of i over j
7	Very strong importance of i over j
9	Absolute importance of i over j
2,4,6,8	Intermediate values

Scale 2: To measure the companies' current and target performance in terms of the WHATs: To measure the companies' current and target performance in terms of the WHATs by the entropy method, a 9-point scale is used. In the proposed scale, there are five linguistic terms along with corresponding numerical values. A more practical approach is to capture customers' opinions using linguistic assessments. For example, rather than using numbers 1 or 5, "very low" or "very high" are used to capture customers' perception.



Scale 3: To measure the relationship between each WHAT and each HOW: To measure the relationship between each WHAT and each HOW, a 1-3-5 point scale is used where the value '5' indicates a strong relationship, '3' means a moderate relationship and '1' denotes a weak relationship between the WHAT and HOW. The suggested scale is presented below.

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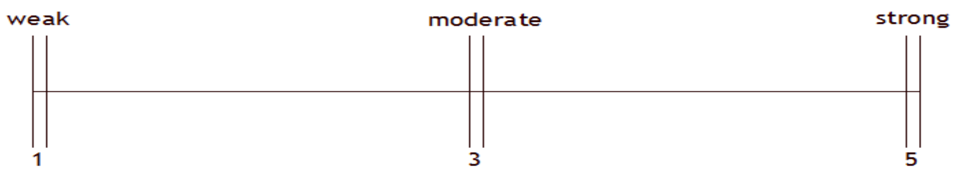

3.2 The stepwise procedure of AHP

The Analytic Hierarchy Process (AHP) is a multiple criteria decision-making tool for organizing and analyzing complex decisions. This widely applied method was developed by Thomas L. Saaty to make complex decisions and rank different alternatives (Saaty, 1986). This method is used to model an unstructured problem into hierarchical forms of elements to make decisions. The AHP has many application areas such as product development, project management, supply chain, business and research (Rao & Pawar, 2018; Anjomshoae et al., 2019; Yap et al., 2018). In this study, AHP has been used to calculate the relative importance of the customers' requirements which are necessary to develop a QFD model.

The stepwise procedure of the AHP is as follows:
Step 1: Construct the structural hierarchy.

Step 2: Construct the pair-wise comparison matrix.
Assuming n attributes, the pair-wise comparison of attribute i with attribute j yields a square matrix $A_{n\times n}$ where a_{ij} denotes the comparative importance of attribute i with respect to attribute j. In the matrix, a_{ij} = 1 when i = j and $a_{ji} = 1/a_{ij}$.

$$
\begin{array}{c|cccccc}
J & 1 & 2 & \ldots & k & \ldots & n \\
\hline
i \quad 1 & 1 & a_{12} & \ldots & a_{1k} & \ldots & a_{1n} \\
2 & a_{21} & 1 & \ldots & a_{2k} & \ldots & a_{2n} \\
\vdots & \vdots & & & & & \\
k & a_{k1} & a_{k2} & \ldots & 1 & \ldots & a_{kn} \\
\vdots & \vdots & & & & & \\
n & a_{n1} & a_{n2} & \ldots & a_{nk} & \ldots & 1 \\
\hline
\text{Sum=} & y_1 & y_2 & \ldots & y_k & \ldots & y_n
\end{array}
$$

Step 3: Calculate the geometric mean from elements of the row.

$$b_k = [(a_{k1}).(a_{k2}) \ldots\ldots (a_{kn})]^{1/n} \quad (3)$$

Step 4: Calculate the normalized weights.

$$x_k = \frac{b_k}{\sum_{k=1}^{n} b_k} \quad (4)$$

Step 5: Calculate the Eigenvector & Row matrix.

$$E = N^{th} rootvalue \Big/ \sum N^{th} rootvalue$$

$$Rowmatrix = \sum_{j=1}^{n} a_{ij} * e_{j1}$$

Step 6: Calculate the maximum Eigen value $\lambda_{\max}$.

$$\lambda_{\max} = Rowmatrix \big/ E$$

Step 7: Calculate the consistency index & consistency ratio.

$$CI = (\lambda_{\max} - n) \big/ (n-1)$$

$$CR = CI \big/ RI$$

Where n and RI denote the order of the matrix and the randomly generated consistency index, respectively. If CR $\leq$10%, the criteria or alternative are accepted. Otherwise, the criteria or alternative is rejected.

3.3 The stepwise procedure of the entropy method

Entropy can be defined as a measure of the number of difference or vagueness.
The stepwise procedure of the entropy method is presented as follows:

Step 1: Construct a customer comparison matrix of all WHATs.

$$A_{N\times L} = \begin{matrix} WHATs \\ W_1 \\ W_2 \\ W_3 \\ \cdots \\ \cdots \\ W_n \end{matrix} \begin{bmatrix} a_{11} & a_{12} & a_{13} & \cdots & \cdots & a_{1l} \\ a_{21} & a_{22} & a_{23} & \cdots & \cdots & a_{2l} \\ a_{31} & a_{32} & a_{33} & \cdots & \cdots & a_{3l} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & a_{n3} & \cdots & \cdots & a_{nl} \end{bmatrix}$$

where a_{nl} denotes the performance of company l's product on the customer need W_n.

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Step 2: Determine the probability distribution of each WHAT by dividing the score of the evaluation needs with the total score.

$$p_{nl} = a_{nl} / \sum_{l=1}^{L} a_{nl}$$

Step 3: Calculate the entropy of each WHAT.

$$E(W_n) = -\emptyset_L \sum_{l=1}^{L} p_{nl} \ln(p_{nl})$$

Step 4: Determine customer competitive priority ratings.

$$e_n = E(W_n) / \sum_{n=1}^{N} E(W_n)$$

4. An illustrative example

In this section, a case study of the quality improvement of a blending machine produced by the Walton group is presented to illustrate the concepts and computations of the proposed AHP and the entropy based HOQ model for prioritizing technical measures. The authors chose this company because it is the highest exporting Bangladeshi enterprise in the field of electronics and delivers versatile products like refrigerators, blenders, freezers, air conditioners, LED/LCD televisions, motorcycles and smart phones. The blender by Walton has gained popularity among Bangladeshi customers due to its low cost and high performance. The company wants to make an improvement in the proposed product to raise its market share. The basic idea is to (i) identify what the needs of the customer (WHATs) are and determine the final importance using the Analytic Hierarchy Process (AHP) and entropy, and (ii) satisfy the needs of the customer with the appropriate technical measures (HOWs) and prioritize the important ones for further developments.

4.1 Acquiring the customer requirements for the HOQ

First, the company must know who their potential customers are. Twelve focus groups were selected through a market survey and the company's sales network to help identify the customer requirements. The focus groups were interviewed personally and their expectations were captured using the customers' words. Eight requirements were identified from the field survey and the internet to represent the largest concern of the customers (Zikrillah). The features are 'proper blending' (CR_1), 'easy to clean' (CR_2), 'less vibration' (CR_3), 'easy to use' (CR_4), 'less energy consumption' (CR_5), 'less heat' (CR_6), 'specific measurements' (CR_7), and 'multiple operations' (CR_8).

4.2 Measuring the relative importance of the customer requirements (WHATs) through AHP

It is not likely that the selected eight customer requirements (WHATs) have the same importance to the customers. Once the customer needs are identified, the next task is to determine the level of importance of the customer expectations in order to develop the HOQ model. In this research, the AHP has been used to measure the relative importance

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of these eight customer requirements. Twelve focus groups expressed their opinions about these eight customer requirements using Saaty's scale, and pair-wise comparison matrices were constructed based on these opinions. Then, an aggregate pair-wise comparison matrix was developed from the geometric means and normalized weights for all of the CRs that were estimated using the necessary formulas. The author was satisfied with the result as the value of the consistency ratio (6.9%) was below the value (10%) suggested by Saaty. All of the calculations are presented in Table 3.The results revealed that the normalized weights ranged between 0.03-0.28. The most demanded attribute was 'proper blending' with a fundamental importance weight of 0.28 which was followed by 'less energy consumption'. The 'multiple operations' requirement was the least expected.

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Table 3
The fundamental importance of the CRs by AHP method

Attributes	CR_1	CR_2	CR_3	CR_4	CR_5	CR_6	CR_7	CR_8	Geometric mean	Normalized weight
CR_1	1.00	5.00	3.33	3.33	2.00	3.67	6.00	3.00	3.04	0.28
CR_2	0.20	1.00	0.33	0.29	0.20	0.33	3.00	0.20	0.41	0.04
CR_3	0.31	3.00	1.00	0.33	0.27	1.33	3.33	0.24	0.74	0.07
CR_4	0.31	3.67	3.00	1.00	0.78	3.33	4.67	0.44	1.44	0.13
CR_5	0.67	5.00	4.00	1.67	1.00	3.33	5.00	1.00	2.09	0.20
CR_6	0.29	3.00	0.89	0.31	0.31	1.00	3.33	0.29	0.72	0.06
CR_7	0.17	0.33	0.31	0.22	0.20	0.31	1.00	0.20	0.29	0.03
CR_8	0.31	5.00	4.33	2.67	1.00	3.67	5.00	1.00	2.06	0.19
Total	3.25	26.00	17.19	9.81	5.75	16.97	31.33	6.37	10.78	1.00
Consistency ratio= 6.9 % < 10%										

4.3 Measuring the improvement ratios of the CRs

The main competitors of the Walton Company in Bangladesh (represented as Co_1 for easy understanding) which produce a similar type of blending machine were identified. To preserve confidentiality, the names of the companies have been kept secret and they are referenced as Co_2, Co_3, Co_4, and Co_5. The company asked twelve focus groups to rate the satisfactory estimation of its own product and the four competitors' similar products in terms of eight WHATs using a 1-9 scale to understand the market and relative market position of the company, and to determine the priority ratings for further improvements. According to the customers' assessment of the relative performance of all of the companies' similar products in terms of the eight requirements, a 5×8 customer comparison matrix was formed by averaging the assessments of the twelve customers. The elements of the matrix are shown in Table 4. Based on the available resources and the relative performances of the five companies on the eight CRs, the company can set satisfactory estimation goals of those CRs for further improvement. After various considerations, future goals were set which are shown in the sixth column of the customer comparison matrix. Note that all of the performance goals are higher than company Co_1's current performance level listed in the first column of the matrix. The aggregated comparison matrix is now the input of the entropy approach. Using the necessary formulas, the probability distribution and entropy of each customer requirement were estimated. After getting all entropies of the eight WHATs, a set of competitive priority ratings of these CRs were determined and shown in the last column of Table 4.

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Table 4
Competitive comparison matrix of satisfactory estimation

	Co_1	Co_2	Co_3	Co_4	Co_5	Satisfactory estimation goals	Set of priority ratings
CR_1	6.83	5.83	7.83	8.08	4.58	7.50	0.125
CR_2	6.50	6.58	7.25	6.92	4.83	7.25	0.126
CR_3	5.75	5.58	7.08	7.42	4.42	6.50	0.125
CR_4	6.33	5.50	6.33	5.67	6.67	7.00	0.124
CR_5	5.58	6.17	7.33	7.17	5.17	6.50	0.125
CR_6	5.75	5.33	6.83	7.75	4.08	6.50	0.124
CR_7	6.25	6.17	6.17	6.17	6.17	7.00	0.125
CR_8	6.67	5.75	7.67	7.83	4.00	7.50	0.125

Based on the current performance level and satisfactory estimation goals of the eight CRs, the improvement ratios were determined. The ratios are 1.097, 1.115, 1.130, 1.105, 1.164, 1.130, 1.120, and 1.125. The analysis revealed that 'less energy consumption' (CR_5) was the highest improvement ratio for the Walton group followed by 'less vibration' (CR_3), and 'less heat' (CR_6). It indicates that the current performance of company Co_1 with respect to CR_5, CR_3, CR_6 is much poorer than the performance of most of its competitors.

4.4 Measuring the final importance of the customer requirements

After determining the fundamental importance of the CRs, a set of priority ratings and improvement ratios, the final importance of the CRs was calculated. A graphical representation is shown in Figure 4. From the diagram, it is quite obvious that the 'proper blending' feature should be the most important concern of the company to meet customer demands. The second highest requirement is 'less energy consumption' which is followed by 'multiple operations'.

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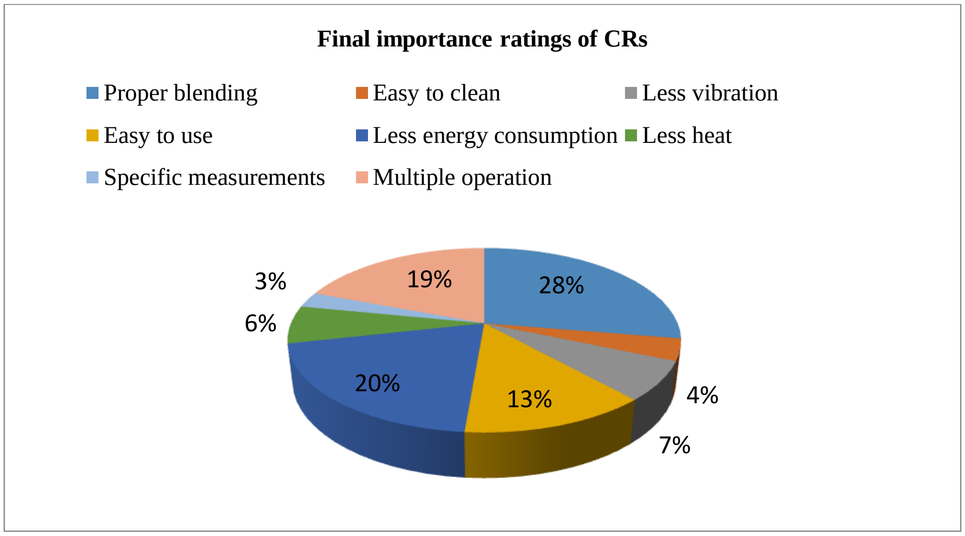

Figure 4 Schematic diagram of final importance ratings of CRs

4.5 Establishing the design requirements

This part of determining the appropriate design characteristics is the most time consuming as well as the most challenging. This process involves the experts using their knowledge and experience to identify the measures. After careful consideration, the design team of the company proposed nine technical measures that could help translate WHATs into HOWs. Table 5 summarizes the proposed design requirements that could help meet the customer requirements.

Table 5
Competitive comparison matrix of satisfactory estimation

Serial no	Design requirements
1	Proper design of the blender
2	Glass jar material
3	Electrical properties
4	Mechanical properties
5	Visible indicator
6	Depth of the container
7	Ergonomics
8	Speed level
9	Jug capacity

4.6 Building a QFD matrix

At this stage, an interrelationship matrix between each CR and EC was formed using scale 3. The above steps complete the HOQ matrix to improve the quality of the product.

The corresponding tables of results, after appropriate arrangement, formed a HOQ that could link customer needs to technical considerations. Figure 5 shows the complete HOQ matrix for the blender. From the HOQ matrix, the final importance weights of the technical measures were determined. The last row of Figure 4 shows the importance weights of the HOWs (percentage score) which range from 3.304 to 26.657. The highest priority was the 'electrical properties' attribute, and the second priority was the 'speed level'. The design requirement 'depth of the container' had the lowest weight.

		Design characteristics												
Customer requirements	Fundamental Importance	proper design of blade	Glass jar material	Electrical properties	Mechanical properties	Visible indicator	Depth of the container	Ergonomics	Speed level	Jug capacity	Improvement ratios	Sales point	Final importance weight	Percent score
CR_1	0.282	•	◊	•	○	○		○	•	○	1.097	0.125	0.039	27.857%
CR_2	0.037	○	•				○	○			1.116	0.126	0.005	3.571%
CR_3	0.068	○	○	•	•			○	○		1.13	0.125	0.010	6.856%
CR_4	0.133	○	○	•	•	•	○	•		◊	1.105	0.124	0.018	13.007%
CR_5	0.194			•	○						1.164	0.125	0.028	20.147%
CR_6	0.066			•	○			◊	•		1.13	0.124	0.009	6.601%
CR_7	0.027		○			•	◊			○	1.12	0.125	0.004	2.698%
CR_8	0.19	•		•	•		○		•		1.125	0.127	0.027	19.376%
Score (Sum ∑= 10		4.954	1.277	8.446	5.170	2.249	1.106	2.385	5.051	1.047				
Percent score(		15.636	4.030	26.657	16.316	7.099	3.490	7.528	15.941	3.304				

Figure 5 QFD matrix for blending machine

5. Results and discussion

In this research, the objective of the integrated QFD framework is to identify the design requirements which are most important to meet the customers' expectations of a specific product. The results from the above analysis revealed the final importance weights of the technical measures (HOWs) and also showed which HOW the design team should focus on to improve customer satisfaction and market share. The percentage score of the technical attributes (HOWs) is graphically shown in Figure 6 and reveals their rank. Figure 6 shows that the most important attribute is 'electrical properties' which is followed by 'mechanical properties'. Therefore, the design team should increase their focus on these attributes to improve the current product.

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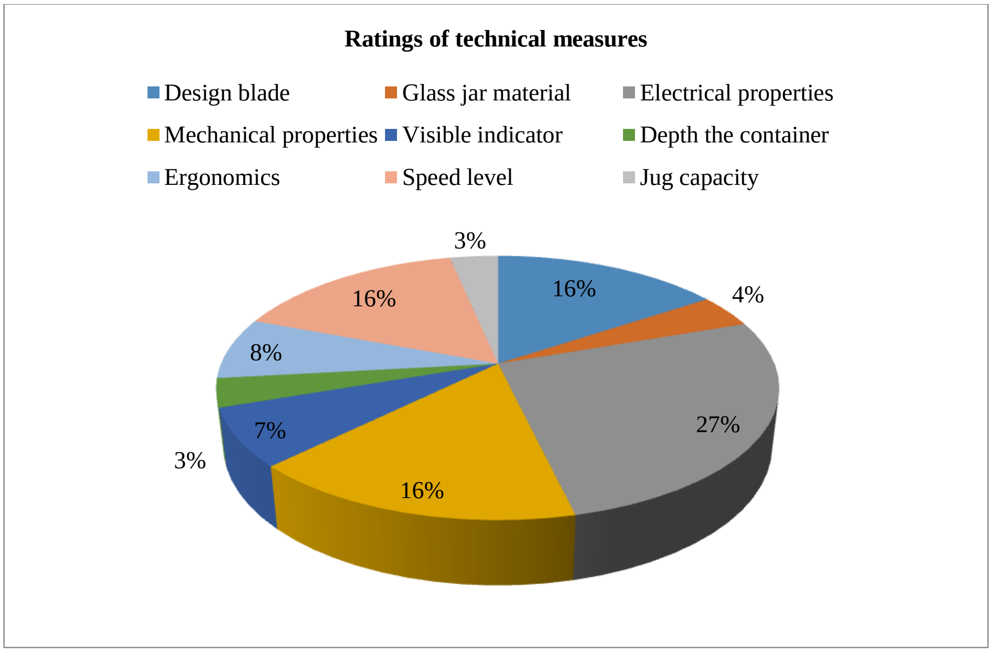

Figure 6 Ratings of the technical attributes

6. Managerial and practical implications

This research contributes to the literature by developing a structured framework that helps identify customers' requirements and uses them to prioritize the design requirements to improve the quality of a product. The decision makers at the product design stage can use this prioritization to refine the product which can help them attract and retain customers.

The managerial implications of this research are summarized below:

- ***Developing a strategic policy for product quality at the Walton Company, BD:*** To increase the market share as well as gain loyalty from customers, it is essential to formulate a strategic policy to incorporate the prioritized design requirements into the existing product. This research can help a product designer concentrate on these design requirements and adopt them into their current practice of service.

- ***Arranging different training programs:*** Customer satisfaction is the key driver for any successful business. To be sustainable in a competitive market, different training programs must be offered to increase the skills of employees. This study will help managers raise funds as well as arrange training programs to capture the customer needs and translate them into design needs.

- ***Developing organizational vision and managerial policy to develop technology:*** A clear and structured organizational vision is very crucial. This research will help managers formulate a company vision and managerial policy to implement the proposed framework.

7. Conclusion

In this paper, an integrated framework based on a QFD that combined the AHP and entropy methods was proposed to identify customer requirements and design characteristics and help achieve an effective evaluation of the final design solution for product development. To improve the conventional HOQ prioritization process, the proposed approach helps by (1) determining the degree of importance of customer requirements through the AHP multi-attribute decision process, (2) assigning the customers' priority rating using the entropy method rather than a conventional approach, (3) determining the company's goals and improvement ratios using entropy rather than a the conventional approach. To validate the proposed methodology, the integrative decision approach was applied to a blending machine produced by the Walton group who wants to improve the quality of the current product through a systematic customer-driven approach. This proposed framework has revealed 8 customer requirements, and there are 9 design characteristics that were considered against these 8 requirements. Five companies were considered for entropy. The final importance of the customer requirements obtained from the AHP approach revealed that the criteria 'proper blending' was the most demanding customer need among the eight proposed requirements. Among the nine technical measures, 'electrical properties' had the highest priority weight and therefore should be focused on to satisfy the customer demands. The analysis allowed the Walton group to measure their current market position and find ways to plan for the future that could help increase market share. It also allowed the company to determine the design requirements that they should focus on in order to keep their customers satisfied. In the future, fuzzy logic could be incorporated into the HOQ matrix to capture the customers' expectations.

7.1 Limitations of the research

This study had some limitations which could be mitigated in future. For example, in this study, only the eight most appealing customer requirements were considered for evaluation. Second, the feedback was collected from 12 focus groups which might not reveal the real picture of the product. Third, a non-fuzzy MCDM method (AHP) was used to measure the importance of the customers' needs. Last, only four leading competitors were considered for the evaluation process. The limitations can provide a framework for future research.

7.2 Direction of future research

In the future, more customer needs could be considered. The impact and interaction among these factors could be assessed using other MCDM techniques like VIKOR, PROMETHEE, etc. Also, in the future a fuzzy environment could be considered. More competitors could be considered to measure the improvement ratios of the customer requirements. The proposed method could be applied in other industries such as furniture, spinning mills, ship building, and pharmaceutical.

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