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FUZZY QFD: DESIGNING A MATHEMATICAL MODEL FOR QUALITY FUNCTION DEPLOYMENT BY FUZZY METHOD

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Abstract

Nowadays, the global competition has been intensified by rapid changes in technology and the variety of production. It has caused more emphasis on the role of continuous improvement of performance as a competition and strategic requirement in many organizations in the world. Quality improvement is related to improvement of engineering characteristics, technical requirements, and corrects understanding of Customers' Requirements (CRs). Recognition of customer technical requirements is necessary for improvement of product technical characteristic. Quality Function Deployment is a powerful instrument for quality improvement and product development and establishing a customer oriented system. In this research, a combining frame of Quality Function Deployment (QFD)

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and Goal Programming (GP) has been designed to show fulfillment level of DR(s), in this framework fuzzy Kano model has been used for degree of CR(s) and Waserman's formula for normalizing of house of quality. This framework can support multi goals optimization (increasing satisfaction customer, decreasing of the cost and technical difficulty). Main question of the research is: What is Mathematical model of quality function deployment (QFD) with the fuzzy approach? Finally, the framework has been used in Cement Company of Larestan for final evaluation.

Introduction

Necessity to meet growing needs and expectations of customers and final consumers and close competition in national, regional and global market on one hand and increasing the supply of products in global markets on the other hand, has led the producers, to maintain and increase their market share by identify needs and expectations of customers to satisfy their customers. Because the quality means customer satisfaction and ultimately is assessed by customer, producing qualified products to supply to marketplace is necessary. So the organizations need some tools to achieve it. Quality Function Deployment (QFD) is one of the total quality management tools.

QFD is a managerial tool that contributes to focus on customer needs through a comprehensive design and product development cycle. However in the first stage, design requirements (DRs) or technical requirements (TRs) are identified and used by product design team according to the company strategic goals.

QFD is an intersection planning tool used to help the product development team. This study applies mathematical and Operations Research models in the cement industry to identify all the factors affect on choosing technical requirements, the technical requirements with top priority to be considered, for maximizing customer satisfaction.

Today, many companies are competing in the cement industry, as far some of them have been able to expand their market share in the national and international markets. Therefore, implementation of quality techniques such as QFD in new businesses such as Larestan Cement Company to offer a quality product and gaining market share is very important. Moreover, using Kano model combined with QFD model leads to identify and classify customer needs. The fuzzy set theory combining to these tools is very useful for considering human judgments. Despite the previous studies, it seems essential to develop a customized new model that can be used in the Iranian cement industry, in this research fuzzy techniques will be added to complete the previous models. Main purpose of our study is to purpose a mathematical model of QFD, since most of our data are verbal, this study tried to integrate QFD and mathematical models and fuzzy model of QFD be taken into consideration. Determining the decision variables and constraints is also sub-purpose of this model. This research tries to transfer outcomes of scientific study from fundamental research to technology field.

Literature Review

Since Human creation, he has dealt with the “quality”. For example, in house building, testing weapons suitability and making tools. History of science shows early twentieth century is beginning of scientific quality and quality system development.

Quality Definition

Today, quality overcast most aspects of our lives. Willingness to quality is due to industries and organizations around the world which are trying to achieve a philosophy that its goal is obtaining the quality far from the expected (Walsh et al. [4]).

Quality as “fitness for use” has defined by Juran and Grayna [9] and Crosby [18] in the same definition introduces the quality as “conformity with the requirements”.

According to Feigenbaum [3] quality is perfect combination of all the features of goods and services that is customer friendly in consuming time. Garvin [6] shows the quality in the eight fundamental dimensions: Performance, features, reliability, adaptability, durability, serviceability, beauty and perceived quality. Understanding the meanings of quality and its affect on competitive market environment is very important for organizations.

Total Quality Management (TQM)

After paying attention to the quality in the production and service field, quality control was introduced. But the quality control did not meet completely human penchant to produce goods and provide services that bring them higher quality. So a new concept called “TQM” was introduced. Chen and Chen [8] defined TQM as a comprehensive management tool to promote organizations competition and maximize market share in related industries. Berry [19] introduces TQM as a comprehensive emphasis on meeting on customer expectations that reduces the cost of poor quality by establishing a management system and new organizational culture. Quality management is a long process that relies on continuous improvement. Problem definition, problem solving, group working and quality circles are most important aspects of the movement toward continuous improvement. Successful implementation of TQM can be created with principal challenges and changes in organizational culture (Zairi [16]).

Quality Function Deployment (QFD)

Quality function deployment (QFD) emerged in Japan in the 1970s and it was not until 1980s that western countries began to appreciate is as a technique and using it as a tool for decision making purposes (Mehrjerdi [23, p. 388]). Historically, formulating concepts of QFD has been started by Japanese industries. In late 1960s Ishihara developed opinion of QFD and its applications for Matsushita. However, the first method analyst who called for using it during the product design process was Akao in 1969. In 1972, Akao published an article about new method and called it “QFD”. Attractive goods for consumers, increase sales and economic rates and social successes will be gained through exact customer physical, cultural, social and technical needs. Setting a system that transfer customer requirements to design and production sectors of organization is recognized as QFD.

Chen and Weng [12] define QFD as product development process that led to obtain the highest level of customer satisfaction or systematic way to deliver customer’s voice to final product through product planning, production and engineering stages for achieving the highest level of customer satisfaction. Another researcher knows it as a method to translate the customer requirements to activities products and services development activities (Lee et al. [22]). According to Lee et al. [22] QFD is a concept that transfers customer requirements to specific technical requirements for each stage of production and development of product. New studies show QFD as a useful mechanism to identify business priorities and it can be very effective strategic planning tool [1].

The function of QFD can be summarized in two dimensions as follows:

- QFD translates customer requirements into technical specifications of product.

- QFD determines the quality activities proportionate to the technical specifications of product.

Benefits of Quality Function Deployment (QFD)

QFD is one of the techniques that emphasize on customer satisfaction from the beginning and enable the firms to solve quality problems. QFD helps the companies to maintain their competition with three strategies: reduce costs, increase income and decrease production time (reduce cycle time).

According to the Benner et al. [14] the main advantages of QFD are:

1. Analyzing and prioritizing of demands and customer requirements.
2. Promoting the teamwork culture and improving inter organizational communication.
3. Reducing complaints and increasing satisfaction of customers due to translating their requirement to product characteristics.
4. Better use of information and documents.

House of Quality (HOQ)

House of quality (HOQ) is one of QFD repetitive process matrixes. HOQ is based on idea that products should reflect the customer desires.

HOQ is used by multifunctional teams in companies for marketing, design engineering, production engineering and other functions. Generally, HOQ provides a foundation that all sectors can link their opinions about a product. Especially HOQ defines the relations between requirements based on different views. QFD uses four matrixes to integrate information needs (knowledge). HOQ is the first matrix which is applied by a team for understanding customer requirements and translating these requirements to the engineering voice (Temponi et al. [5]).

Kano Model

In the late 70s, Professor Kano (Rica School in Tokyo) and his colleagues adjusted the concept of the quality based on hygiene-motivation theory of Herzberg research.

Since its introduction in the 1980s, Kano's model of attractive quality (Kano et al. [17]) has become one of the most popular quality models among marketing/management practitioners and researchers in a wide range of industries (Mikulic and Prebežac [10, p. 46]). While many previous definitions of quality, considers quality as a single dimension (good or bad, big), Kano defined quality as a two-dimensional concept. These are noted below:

1. Level of Product or service Good yield.
2. User satisfaction level.

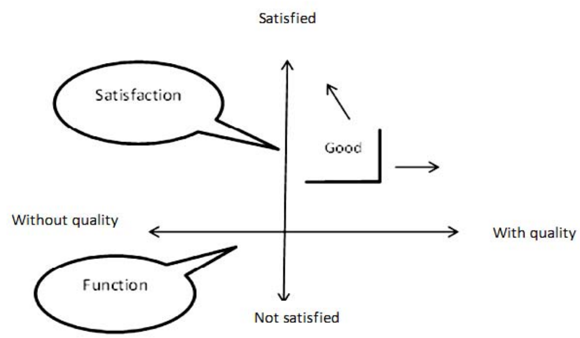

Figure 1. Kano model.

Vertical axis illustrates satisfaction or customer satisfaction and horizontal axis shows quality rate. Intersection of horizontal and vertical axes indicates the balance of customer satisfaction and dissatisfaction. Right horizontal axis represents the expected quality requirements meet completely and left horizontal axis represents a point which does not provide expected quality and no obligation of desired quality in any product or service.

These two factors associated to a unique five-defined quality as the Basic/must-be quality, quality performance/one-dimensional, and Attractive quality, Indifferent quality, Reverse quality (Lee et al. [22]).

Basic Quality: This attribute to basic Quality or basic customer need that will have little effect on customer's satisfaction if it is fulfilled but it will cause Customer dissatisfaction if it does not completely supply, because the expectations of customer. These features must be in the product (Mehrgan and Ghasemi [15]). The basic needs of Kano’s model are like biological Maslow needs while they are not satisfied; they will not shift to their upper levels.

Functional quality: These attribute results in satisfaction when fulfilled and dissatisfaction when not fulfilled. Unlike basic demands this class is verbal and directly will be stated by customers and consumers. Customer information about the functional requirement is often called “customer voice” because the customers are interested talking about this (Matzler and Hinterhuber [11]).

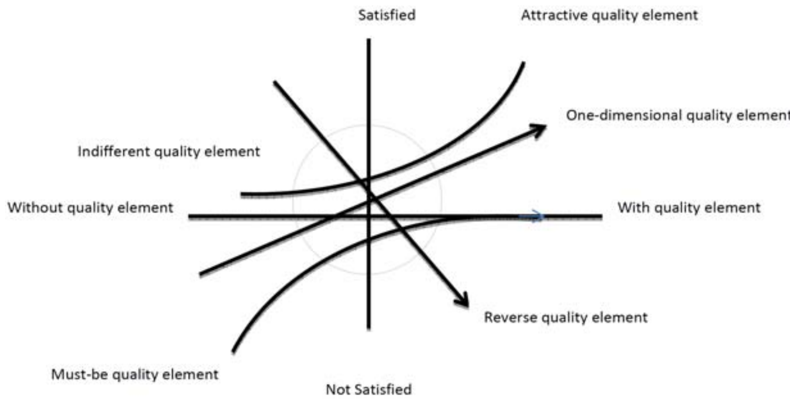

Figure 2. Source: Kano model (Lee et al. [22]).

Attractive Quality: These attribute provide satisfaction when achieved fully but do not cause dissatisfaction when not fulfilled. These are attributes that are not normally expected. In this type of quality, customer's tornado is due to the customer encounter with designs and specifications in the product or service that it does not prospect or even it seems impossible (Mehrgan and Ghasemi [15]). Note if this type of needs to be considered to produce a product for market in high Volume, this quality characteristics shortly will be copied by other competitors and it will get a functional requirement and demand or even a basic one (Babaei [13]).

Indifferent quality: There are some of the features in a product that they are not known as a quality by customers and no impact on their satisfaction. So this bunch is called *indifferent quality requirements* (Lee and Huang [21]).

Reverse Quality: There are some characteristics in products that their implementation not only does not meet customer satisfaction, but also lead to customer dissatisfaction and will be caused reducing in the sale of goods (Lee and Huang [21]).

Tools Used in the Kano Model

Recently, it has been proven that the two-dimensional quality model provided by Kano is an effective tool for analyzing customer requirements.

Kano model uses functional and non-functional questionnaires as well as assessment Table 5 by 5 (5×5) as a leading tool. Kano model discover customer comments about the products and services from the questionnaires, and the data offers a base to improve customer satisfaction.

If you can purchase airline ticket online, how do you feel? (Functional question)	1. I like it that way 2. I expected it that way 3. I am neutral 4. I can accepted it to be that way 5. I dislike it that way
I like it that way I expected it that way I am neutral I can accepted it to be that way I dislike it that way	1. I like it that way 2. I expected it that way 3. I am neutral 4. I can accepted it to be that way 5. I dislike it that way

Customer requirement		Answer to dysfunctional question				
		accept	Expect	Neutral	accept	dislike
Answer to Functional Question	Like	Q	A	A	A	O
	Expect	R	I	I	I	M
	neutral	R	I	I	I	M
	Accept	R	I	I	I	M
	Dislike	R	R	R	R	R

CR	A	M	O	R	Q	I	total	Category
1	1						1	A
2								
3								
……								

Note: A = Attractive; M = Must-be; O = One dimensional; R = Reverse; Q = Questionable; I = Indifferent.

Figure 3. Source: Mikulic and Prebežac [10, p. 49].

Needs and demands, whether basic, single-dimensional and exciting are customer oriented. We can classify them in questionnaire.

For any product pair of questions is used. The first question is associated with customer reaction if the product has the feature (functional form of questions). The second question is connected to customer reaction if the product does not have the feature (non-functional question). Then questions sets, “commenting customer opinion” are analyzed. Questionnaires are evaluated in three stages.

After combining non-functional and functional responses in the evaluation table, unique and special results of product is classified in the results table that shows the distribution of demand. The next stage is interpretation and analysis of results (Xu et al. [20]).

As a rule, however the answers with more than one classification must be analyzed for different interpretations of them.

In this case, this distribution can be explained according to the fact that customers in different sectors have different expectations of the product. If the questionnaire includes a variety and sufficient guidance customer, the results could be used as a basis and an ideal base in different market sectors (Matzler and Hinterhuber [11]).

Evaluation Law $M > O > A > I$

If the need and demand for special products cannot unequivocally takes place in various classifications. Evaluation rule $M > O > A > I$ will be very helpful. When product development decisions are performed, initially consider characteristics and properties that are most effective on product quality. Needs should be objective unless they will deter customer satisfaction.

Customer satisfaction will be achieved when noticeable and attractive needs are complied. In fact, final factor is important for the customer and it can be considered in the questionnaire by him/his.

If they meet two or three catchy and substantial needs, notice them as factors that the customer is interested to them, its outcome is a pack of characteristics of product with characteristics that are not old and rusty (Matzler and Hinterhuber [11]).

Fuzzy Kano Questionnaire

In traditional Kano questionnaire, giving unique answers disappear the ability of complexity reflection, so, if people use membership function for expressing the degree of their feelings based on their options, the answers approach to real human thought. Fuzzy sets are characterized by the membership function of the form $X[0, 1]$ (Azar and Darvishi [2]). Then collecting information based on fuzzy style is the first step (Lee and Huang [21]). Fuzzy logic allows taking into account a different meaning that may be given to the same linguistic Expression (Khademi-Zare et al. [7, p. 749]).

Both traditional and Fuzzy Kano questionnaire use functional and non-functional models to respond to customer feelings about the product. But the biggest difference is the respondent only allowed to give an answer and express only superficial feelings about the product in traditional Kano questionnaire while the fuzzy Kano questionnaire has more flexibility this way and can achieve more information about the product.

Fuzzy Kano Evaluation Questionnaires

U and *V* are complete set of questions, positive and negative, such that $N = \{N_1, N_2, ..., N_n\}$ and $P = \{P_1, P_2, ..., P_p\}$ a set of *N* and *P* is language variable for the *U* and *V*, they create the two-dimensional quality model of $P * N$.

The membership function of each sets of P_i and N_j be normalized as follows (Lee and Huang [21]):

$$m(D)_{kj}\left(\sum_{j=1}^{d} m(D)_{kj} = 1\right),$$

$$m(F)_{ki}\left(\sum_{i=1}^{f} m(F)_{ki} = 1\right),$$

$$G_{ij} = \sum_{k=1}^{r} m(F)_{ki} \otimes m(D)_{kj}, \tag{1}$$

T_h is sum of S_{xy} that X, Y belong to hth HOQ set of $S_{x,y}$ on evaluated page. For example, if

$$F = \{1, 0, 0, 0, 0\},$$

$$D = \{0, 0, 1, 1, 1\},$$

$$m(F) = \{1, 0, 0, 0, 0\},$$

$$m(D) = \{0, 0, 0.333, 0.333, 0.333\},$$

$$G = \begin{bmatrix} 0 & 0 & 0.333 & 0.333 & 0.333 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$T = \left\{ \frac{0}{M}, \frac{0.333}{O}, \frac{0.666}{A}, \frac{0}{I}, \frac{0}{O}, \frac{0}{Q} \right\}.$$

Limitations and Advantages of Kano Model

According to Matzler and Hinterhuber [11], the benefits of needs classification based on the Kano model can be expressed as follows:

Exact understanding of the product requirements has most effect on customer satisfaction. Hence with classifying the product requirements to basic, one-dimensional and attractive requirements, it can be focused on sectors of product process, which have most effect on satisfaction of a customer from a product.

If two product demands simultaneously cannot occur due to financial and technical reasons, these criteria and scale could determine the most effect on customer satisfaction.

Basic, one-dimensional and attractive requirements in different parts with different clients, as a rule are predictable. A production can exclusively lead to customer interest and enjoyment from the basic and one. Dimensional requirement and interesting to these requirements is changeable too.

Customer satisfaction in Kano model ideally can be combined with the way of developing operations.

Purpose of Research

Despite the efforts, providing a new model, the model was tested in the Larestan cement industry, using a fuzzy questionnaire. The main goal of this study is presenting a mathematical model for QFD. Since most of our data are verbal so we consider a fuzzy QFD model. Finding the decision variables and restrictions of model are sub-goals of this study. As mentioned, main question of the research is:

What is Mathematical model of quality function deployment (QFD) with the fuzzy approach?

Subsidiary research questions are:

- What are decision variables of Mathematical models in the fuzzy QFD?

- What are the constraints of Mathematical fuzzy QFD model?

Statistical Population

The study applied mathematical models and operations research in the cement industry (A) to recognize all affecting factors on choice of technical requirements. (B) to determine technical characteristic which should be considered for maximizing customer satisfaction. For this purpose we arranged QFD teams, consisting managers, engineers and statistical experts.

Methodology

In this study, using a goal programming (GP) model as a decision-making tool has been preferred because it can combine multiple objectives and search for the maximum membership degree of objective. The GP characteristic would enable us to engage multiple targets, such as cost and hard work limits in design process. Using Kano model in categorizing customer demands lead to more focus on the attractive needs. So customer being more satisfied.

Overall proposed algorithm can be divided in two stages. In the first stage the house of quality will be completed by experts interviews, then using the fuzzy Kano approach customer demands are categorized based on the Kano model and their importance coefficient are determined, consequently the coefficient of importance of technical requirements to be addressed. In the next stage results of the first stage are combined with a goal programming model to determine the ideal level of design needs. The powerful Kano model with fuzzy approach enables classification of the customer needs into three categories, basic, functional and attractive as one of the main objectives of study. On the other hand it is necessary that the other objectives and design parameters such as cost and hard work constraints for using verbal data set also be considered. Finally, all computational data should provide for formulating GP models.

The stages of (research problem) decision algorithm are summarized as follows:

Step One: To identify customer demands and technical requirements affecting them and to determine their relations (R_{ij}).

It should be noted that the initial list of customer requirements usually is vague and overall and defining them in a standard and clear phrases is essential. Therefore it is necessary that QFD team to specify some of the engineering properties and technical definitions to meet these demands.

The technical specifications and customer demands through the fuzzy Kano questionnaire are obtained. These technical definitions make roof of HOQ.

The customer demands and technical requirements will be determined by more interviews and conversation with the QFD team members. Then they will be used after the adjustment and getting normalized by the Waserman formula.

Customer demands for studying products of this research (cement) have shown in the table as below:

Table 1. Customer demands for cement

Cement color	Cement health	Cement resistance	Cement adherence	Soft particles
CR5	CR4	CR3	CR2	CR1

These demands are briefly defined as follows:

Soft particles: The chemical reaction rate of water and cement depends on being tiny of cement particles. On the other hand achieving it requires substantial cost.

Cement adherence: The required time for hardening of cement is called the “cement adherence”.

Cement resistance: Mechanical resistance of hardening cement is most important property of cement.

Cement health: Size of cement paste should not change after hardening, because this expansion causes fracture and disorganization of cement. The cement has such expansion property is called unhealthy.

Cement color: For customers darkest cement is excellent and more desirable than the cement has a lighter color. Amount of iron in cement is cause of its darkness. The following table shows the technical requirements.

Table 2. Technical requirements

Cooling speed	Free lime	Magnesium percentage	C3A	Blit phase	Alit phase	Iron	Plaster percentage	Combined charge percentage
DR9	DR8	DR7	DR6	DR5	DR4	DR2	DR3	DR1

Technical characteristics effects on each customer’s needs are different from each other. They are obtained from interview with experts in linguistic terms and are defined in triangular fuzzy numbers as follows:

(0, 0, 0), (0, 0.1, 0.2), (0.2, 0.3, 0.4) and (0.8, 0.9, 1) that are interpreted based on the concepts of “no link”, “poor link”, “medium link” and “strong link”.

Second Step: Determine inter dependence matrix of technical needs by verbal data r_{ij}.

QFD users should not only understand customer demands, but also must be aware to rate of attention to these demands in order to obtain the ideal level of customer satisfaction. In this step, the customer demands are divided in three categories using two-dimensional Kano model and functional and non-functional fuzzy Kano questionnaire; exciting, functional and basic these categories are obtained as follows:

In the model, H indicates a customer who has been questioned from, s and t are options in the questionnaire and f and d show weights which hth customer gives to s and t.

f_s and d_t as Language variables are normalized by using the fuzzy set relations as follows and then two-dimensional quality model is obtained by multiplying two sets:

$$\widetilde{G}_h = \widetilde{F}S_{h,s} \times \widetilde{D}S_{h,t}, \tag{2}$$

$$\widetilde{D}S_{h,t} = d_{h,t}/\sum_{t=1}^{m} d_{h,t}\widetilde{F}S_{h,s} = f_{h,s}/\sum_{s=1}^{n} f_{h,s}. \tag{3}$$

Third Step: Determine the relative importance degrees of customer's demands and classify them by Kano Model $W(CR_i)$.

To calculate the weight of importance of customer demands it should be specified importance degree (d_i) and Overall Rate of Improvement (IR_0^2) and type of needs by Kano classification. Importance degree of each demand is calculated by five ranges and through a questionnaire. For determining the improvement ratio, it should be achieved using ideal satisfaction level (T) and current satisfaction levels (C):

$$IR_0 = \left(\frac{T}{C}\right). \tag{4}$$

Overall Rate of Improvement change to Adjustment Rate of Improvement by applying Kano model as follows:

$$IR_{adj} = (IR_0)^{1/k}. \tag{5}$$

And finally the formula for calculating the weights is as follows:

$$W(CR_i) = \frac{d_i \times IR_{adj}}{\sum_{i=1}^{I} d_i \times IR_{adj}}. \tag{6}$$

Considering that characteristics of softness and color have been defined as the two indifferent characteristics so we will not study them and continue with other three demands, cement health, adherence and resistance. The amount of iron as a technical requirement that only depends on the color of cement also should be removed.

According to the data, calculated overall improvement rate for health, adherence and resistance, are 1.25, 1 and 1.25 and according to table of importance degree of demands, three characteristics of the above are functional based on Kano rank. So, k is equal to 1 for them.

Therefore values of adjusted improvement ratio for these three characteristics will be equal to previous values. Finally the weight of needs is calculated by $W(CR)$ as follows:

$$CR_1 = 0.36, \quad CR_2 = 0.28, \quad CR_3 = 0.36.$$

Fourth Step: Normalizing R_{ij} by Waserman formula.

In order to clarify the relationship between CRs and DRs and between the DRs, Waserman offers following normalizing formula:

$$R'_{ij} = \frac{\sum_{k=1}^{n} R_{ik} r_{kj}}{\sum_{j=1}^{n} \sum_{k=1}^{n} R_{ik} r_{kj}}, \quad i = 1, 2, ..., m, \quad j = 1, 2, ..., n. \tag{7}$$

Normal fuzzy relation can be written as follows:

$$\tilde{\mathfrak{R}}'_{ij} = \frac{\sum_{k=1}^{n} \tilde{\mathfrak{R}}_{ik} \tilde{\gamma}_{kj}}{\sum_{j=1}^{n} \sum_{k=1}^{n} \tilde{\mathfrak{R}}_{ik} \tilde{\gamma}_{kj}}. \tag{8}$$

Membership degree of normal fuzzy relation $\tilde{\mathfrak{R}}_{ik}$ can be demonstrated as follows:

$$\mu_{\tilde{\mathfrak{R}}'_{ij}}(R'_{ij}) = \sup\min\left\{\mu_{\tilde{\gamma}kj}(r_{kj}),\ \mu_{\tilde{\mathfrak{R}}_{ik}}(R_{kj}),\ \forall k,\ j \;\middle|\; R'_{ij} = \frac{\sum_{k=1}^{n} R_{ik} r_{kj}}{\sum_{j=1}^{n}\sum_{k=1}^{n} R_{ik} r_{kj}}\right\}. \quad (9)$$

The fuzzy normal relations $\tilde{\mathfrak{R}}_{ik}$ are calculated by the above formula. To get $\tilde{R}_{ij}$ the bottom and top α cut for $\tilde{\mathfrak{R}}_{ik}$ and $\tilde{\gamma}'_{kj}$ is determined based on their membership function. Membership function is a triangular fuzzy number that easily obtain through the functions linearity. So the HOQ-body based α cuts is as follows:

Table 3. Membership degree of relations between the customer demands and technical requirements

Combined charge percentage	Plaster percentage	Blit phase	Alit phase	C3A	Magnesium percentage	Free lime	Cooling rate	
	0.8+0.1α 1.0-0.1α			0.8+0.1α 1.0-0.1α			0.8+0.1α 1.0-0.1α	Cement adherence
0.8+0.1α 1.0-0.1α	0.2+0.1α 0.4-0.1α	0.8+0.1α 1.0-0.1α	0.8+0.1α 1.0-0.1α		0.2+0.1α 0.4-0.1α	0.2+0.1α 0.4-0.1α	0.8+0.1α 1.0-0.1α	Cement resistance
0.2+0.1α 0.4-0.1α	0.2+0.1α 0.4-0.1α				0.8+0.1α 1.0-0.1α	0.8+0.1α 1.0-0.1α	0.2+0.1α 0.4-0.1α	Cement health

Fifth Step: Determine the cost and hard work measurement by verbal data.

As mentioned, two factors, cost and hard work are effective on improving product quality by using words low, medium and high these factors has been considered.

Table 4. Membership degree of relations between technical requirements according to α cut

Combined charge percentage	Plaster percentage	Alit phase	Blit phase	C3A	Magnesium percentage	Free lime	Cooling rate	
--------								Combined percentage
	--------							Plaster percentage
--------	--------	--------				0.2+0.1α 0.4-0.1α		Alit phase
--------	--------	--------	--------			0.2+0.1α 0.4-0.1α		Blit phase
--------	--------	--------	--------	--------		0.2+0.1α 0.4-0.1α		C3A
--------	--------	--------	--------	--------	--------			Magnesium percentage
--------	--------	--------	--------	--------	--------	--------		Free lime
--------	--------	--------	--------	--------	--------	--------	--------	Cooling rate

Table 5. Linearity relationship of cost and hardworking based on α

Combined charge percentage	Plaster percentage	Alit phase	Blit phase	C3A	Magnesium percentage	Free lime	Cooling rate	
0.0+0.1α 0.2-0.1α	0.0+0.1α 0.2-0.1α	0.8+0.1α 1.-0.1α	0.8+0.1α 1.-0.1α	0.8+0.1α 1.-0.1α	0.8+0.1α 1.-0.1α	0.0+0.1α 0.2-0.1α	0.2+0.1α 0.4+0.1α	Cost
0.0+0.1α 0.2-0.1α	0.0+0.1α 0.2-0.1α	0.8+0.1α 1.-0.1α	0.8+0.1α 1.-0.1α	0.8+0.1α 1.-0.1α	0.0+0.1α 0.2-0.1α	0.8+0.1α 1.-0.1α	0.2+0.1α 0.4+0.1α	Hardworking

Value of each factor could be calculated by different α.

Sixth Step. Formulating and solving Goal programming to determine the level of technical requirements.

The main goal of this research is formulating a fuzzy Goal programming model to choose a combination of DRs for calculating the maximum sum of satisfaction degree of all goals. To determine the estimated level of each DR, regarding to the competitors' analysis and company experts a basic level for every requirement is needed.

The below table shows minimum estimated level of each requirement:

Table 6. Minimum estimated level of each requirement

L8	L7	L6	L5	L4	L3	L2	L1
------	0.5	0.4	0.33	0.56	0.8	------	------

Since access to three requirements: the composition of mill charge percentage, the percentage of gypsum and cooling speed is comfortable and cheap and also in competition with any other design requirements are less effective and meeting them in any level is easy, the corporation has not mentioned minimum level of participation for them. As stated, main goal of this study is formulating a fuzzy GP model for calculating the maximum sum satisfaction degree of all goals. So, three goals including "maximum customer satisfaction", "minimum hard work" and "minimum costs" are considered. Formulated model at the level of $\alpha = 0$ is as follows:

$$\max \sum_j (w_i)^u_{\alpha=0} x_j = 0.23x_1 + 0.16x_2 + 0.23x_3 + 0.18x_4 + 0.14x_5 + 0.06x_6 + 0.3x_7 + 0.12x_8$$

$$\min \sum_j (c_j)^t_{\alpha=0} = 0.8x_3 + 0.8x_4 + 0.8x_5 + 0.8x_6 + 0.2x_7,$$

$$\min \sum_j (T_j)^t_{\alpha=0} = 0.8x_3 + 0.8x_4 + 0.8x_5 + 0.8x_7 + 0.2x_8$$

s.t.:

$$x_3 \geq 0.8$$

$$x_5 \geq 0.33$$

$$x_6 \geq 0.4$$

$$x_7 \geq 0.5$$

$$x_i \leq 1, \quad i = 1, ..., 8. \tag{10}$$

The main model with limitations of top and bottom of each goal is as follows:

$$(Z)_{\alpha}^{t} = \max \sum_{h=1}^{3} \mu_h(x)$$

s.t.:

$$\mu_1(x) = \frac{\sum_{j=1}^{n} (w_j)_{\alpha}^{t} x_j - 0.2474}{1.42 - 0.2474},$$

$$\mu_2(x) = \frac{5 - \sum_{j=1}^{n} (c_j)_{\alpha}^{u} x_j}{5 - 1.672},$$

$$\mu_3(x) = \frac{5 - \sum_{j=1}^{n} (T_j)_{\alpha}^{u} x_j}{5 - 1.752},$$

$$\mu_1(x) \geq \mu_3(x),$$

$$\mu_2(x) \geq \mu_3(x),$$

$$\mu_i \leq 1,$$

$$\mu_i \geq 0, \quad i = 1, 2, 3,$$

$$x_j \geq l_j, \quad j = 1, ..., n,$$

$$x_t, \quad l_j \leq 1, \tag{11}$$

$$(Z)_{\alpha}^{u} = \max \sum_{h=1}^{3} \mu_h(x)$$

s.t.:

$$\mu_1(x) = \frac{\sum_{j=1}^{n} (w_j)_{\alpha}^{u} x_j - 0.2474}{1.42 - 0.2474},$$

$$\mu_2(x) = \frac{5 - \sum_{j=1}^{n} (c_j)_\alpha^l x_j}{5 - 1.672},$$

$$\mu_3(x) = \frac{5 - \sum_{j=1}^{n} (T_j)_\alpha^l x_j}{5 - 1.752},$$

$$\mu_1(x) \geq \mu_3(x),$$

$$\mu_2(x) \geq \mu_3(x),$$

$$\mu_i \leq 1,$$

$$\mu_i \geq 0, \quad i = 1, 2, 3,$$

$$x_j \geq l_j, \quad j = 1, ..., n,$$

$$x_j, \quad l_j \leq 1,$$

$$x_j, \quad l_j \geq 0. \tag{12}$$

For solving the model "Win QSB" was used. By solving 21 linear programming models using the eleven α cut 0, 0.1...1 level of achieving to each goal can be estimated. It means their membership degree (μ_i) and their sum (Z_α^t, Z_α^u) and level of implementation of DR (X_i) are calculated. The following table shows the results:

Table 7. Range of result

μ_2		μ_1, μ_3		X_5		A
U	L	U	L	U	L	
0.88	0.44	0.75	0.30	C	0.57	0.0
0.86	0.46	0.73	0.33	0.76	0.56	0.1
0.83	0.48	0.70	0.34	0.78	0.61	0.2

0.81	0.50	0.67	0.37	0.74	0.62	0.3
0.78	0.51	0.65	0.38	0.79	0.67	0.4
0.75	0.52	0.62	0.40	0.82	0.70	0.5
0.73	0.56	0.60	0.43	0.76	0.71	0.6
0.71	0.58	0.58	0.44	0.78	0.72	0.7
069	0.60	0.56	0.47	0.77	0.73	0.8
0.66	0.62	0.53	0.49	0.75	0.73	0.9
0.65	0.65	0.52	0.52	0.74	0.74	1

Figure 4 illustrates the membership function of each goal:

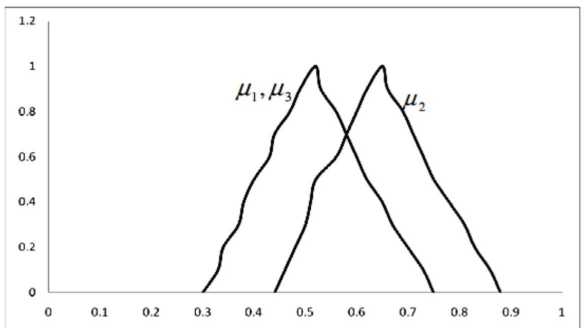

Figure 4. Membership function of each goal.

As it is shown objective functions of G1 and G2 are equal in importance, but the membership degree of G2 is higher than G1 and G3 so that G2's limitations are (.58 and .71) and G1 and G3's limitations are (0.44 and 0.58). Obtaining costs goal is easier than customer satisfactions'.

Solving the model result all X_i except X_5 are crisp and their amount are: 100%, 100%, 80%, 56%, 40%, 100%, and 100%. As previously noted the decision variables $x_i = 100$ mean full implementation of the technical requirements to achieve the best level of quality. Membership's function of technical requirement of X_5 as fuzzy function has been illustrated in Figure 5:

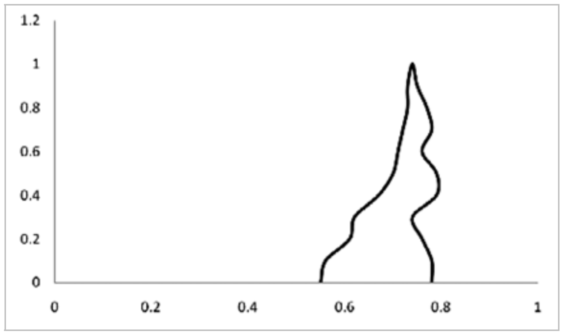

Figure 5. Membership function of X_5 diagram.

Discussion and Conclusion

Implementation of QFD is a time consuming process that requires understanding many concepts, collecting high volume of information and doing a lot of calculation. Definitely a full interpretation and operation in QFD process will facilitate the applications.

In this study, a combined approach of Kano model and GP are presented for solving and formulating design problem in QFD. In addition, for converting qualitative terms to quantitative measures and considering CRs and DRs fuzzy logic has been used. In traditional QFD analyzing and prioritizing customer's opinion are done by experts but in this study fuzzy logic is used to improve weaknesses of traditional QFD in studying customer's requirement and fuzzy questionnaire has been designed for this purpose. In addition by using Kano model we identify and prioritize customer demands. Combining fuzzy logic with Kano model is a new concept in this research. Using fuzzy logic has two fundamental outcomes in this study:

1. Since the human judgments are naturally fuzzy, using fuzzy numbers is more preferable than crisp.
2. QFD team will be able to implement their models freely and more flexibility will be gained by using fuzzy numbers.

In summary, to answer the research question "what is mathematical model of QFD with fuzzy approach?", as it was presented in the mathematical model according to the QFD constraints and objectives in GP model there are three goals, five constraints and eight decision variables.

By changes on the original model to simplify it, other restrictions were added to the model. These restrictions include three restrictions about upper and lower limits for each goal and two others represent increasing the membership degree of cost reduction target and increasing levels of customer satisfaction rather than the hard working reduction and the three constraints on determining membership degree in the interval of zero and one.

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