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An application of Fuzzy Quality Function Deployment to bunkering services

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Abstract

Bunkering is very important for the maritime industry because of the need for continuity of trade, its relation to the energy industry and its great economic value. Today, the volume of the world's bunkering market is around 350 million tons annually. Although there are about 400 major bunkering ports in the world, most of the demand is concentrated in a few strategic ports: when comparing strategic regions of the world, Istanbul has a very small share. With this in mind, this paper aims to demonstrate the current situation of Istanbul and to improve service quality using Fuzzy Quality Function Deployment. Our results show that the criteria which customers look for, in order of importance, are: supply waiting time; bunker quality; usage and availability of barges; duration of bunkering operation; and bunker price and price competitiveness. The steps to be taken to improve service quality are determined as: increase storage facilities and capacities; create a structure that can provide 24/7 bunker supply; and increase importance of bunkering in port infrastructure and management thinking (bunker port concept). It is possible that the findings can be a guide to ship fuel suppliers, especially in Turkey, to improve service quality and increase their fuel sales volume.

Introduction

Maritime transportation is one of the most important transportation methods and has influenced the shape of human history. People have been using marine routes for transportation and commercial activities for thousands of years. Adventurous mariners have also shaped the history of humanity by exploring new continents, thanks to access by sea. For many years, people used manpower and wind power to propel their ships. With the development of steam vessels towards the mid-19th century, solid fuels (coal, wood, etc.) began to be used for ships. Solid fuels were stored in areas called 'coal bunkers'. In the course of time, mariners began to use the term 'bunker' for all types of ship fuels and 'bunker' continues to be a common name for them (Draffin, 2010).

Because of difficulties in using coal as a fuel (large volume, handling difficulties, very high manpower needed for handling, management difficulties of storage, usage and ash handling), entrepreneurs and great naval powers were keen to develop alternative fuels for ships. As a result of these initiatives, from the beginning of the 20th century, petroleum-derived fuels began to be used. Especially after the First World War, the transition to fuels derived from petroleum gained speed. By the 1940s, about half of the all ships in the world were using oil-derived fuels. This rapid transition continued in the following years (Draffin, 2008).

With the industry dominated by petroleum-derived fuels and an increase in sea trade and the number of ships, bunkering services, a constantly growing market, evolved into a large and complex structure. Today, the parties in the bunkering process are basically divided into sellers, buyers and bunker brokers, who sometimes act as intermediaries (Draffin, 2011). The distribution channel of bunkering begins at refineries where fuel is produced, and ends up on the ship, which is described as the buyer. There may be many potential mediators, including traders, bunker brokers and physical suppliers, participating in these chains (Dupre, 2010).

Today, the volume of the world bunkering market is around 350 million tons annually. 70 million tons of these fuels are distillate fuel; in other words, gas oil, while 280 million tons are residual fuel (DTO, 2015). Although there are about 400 major bunkering ports in the world, most of the demand is concentrated in a few strategic ports. Singapore is the world's biggest bunkering port, with highly developed infrastructure on the world's busiest sea routes (OPEC, 2015). According to 2016 statistics, the annual bunker sales of Singapore Port amount to 48.6 million tons (MPA, 2017). Fujairah (UAE) is also one of the world's leading markets; 24 million tons of bunker sales were realized in Fujairah Port according to 2013 statistics. Rotterdam, the largest port of Europe, is also the largest bunkering port in the continent (OPEC, 2015). According to 2016 statistics, Rotterdam's bunker sales were 10.1 million tons (Port of Rotterdam, 2017). Apart from these ports, other leading bunkering ports are Hong Kong, Antwerp, Busan, Algeciras, Panama, Los Angeles/Long Beach and Shanghai. When sales figures are examined, oil demand in the bunkering sector is concentrated in several countries. In 2012, Singapore, China, the United States, the United Arab Emirates (UAE), the Netherlands and South Korea accounted for nearly 60% of the world's bunker demand (OPEC, 2015).

Turkey is located on one of the most important channel and strait transition regions, and plays a decisive role in maritime trade in the world. However, its annual total bunker supply is around 2.5 million tons and its world market share is less than 1%. The main bunkering ports of the country are Istanbul, Izmir, Mersin and Iskenderun. According to 2014 data, Istanbul (Istanbul Strait and Sea of Marmara) has a large proportion of the country's bunker supply, with about 1.5 million tonnes (DTO, 2015).

In this context, the purpose of the paper is to determine the requirements and needs of the parties receiving bunkering services, and to this end, to identify and prioritize improvements to be made to the service provided in the Istanbul region. The paper will provide data which can guide an increase in service quality and market share, by using the Fuzzy Quality Function Deployment (QFD) method.

It is thought that this paper will contribute to the literature because there are not enough comprehensive studies on bunkering services. In addition, the first use of this research method in the bunkering literature increases its importance.

In the second section of the paper, basic information about the QFD is given. In the third section, Fuzzy Logic is discussed. The implementation process is explained in detail, and the findings obtained are given in the fourth section. In the conclusion, the findings are interpreted, limitations of the research are stated, and suggestions are made for future research.

Quality Function Deployment

The concept of Quality Function Deployment (QFD) was developed in the late 1960s. During this period, it was determined that ships made in Japan had problems with manoeuvre, balance and propulsion. The scientific team created to solve this problem created a system that addressed all the stages of the shipbuilding process to meet the specific needs of customers, and these needs were incorporated into this system. Thus, the concept of QFD emerged. There are several definitions of QFD in the literature. According to one of the basic descriptions, QFD aims to provide special methods to ensure quality at every stage of the product/service development process, starting with production design. In other words, it is a method which was developed for the purpose of providing customer satisfaction, and is used for customer demands, design goals and basic quality assurance points throughout the production process (Akao, 1990).

Although the first implementation area was the manufacturing sector, with successful results, it was not long before the service sector began to use the method (Chan & Wu, 2002). Chan and Wu (Chan & Wu, 2002) determined 650 implementations in their literature review. It was observed that QFD had been applied in most sub-fields of the transportation and communication, manufacturing, electricity and electronics, software and service sectors. Implementations in the maritime sector are based on service development, environmental and sustainable maritime use and ship type selection.

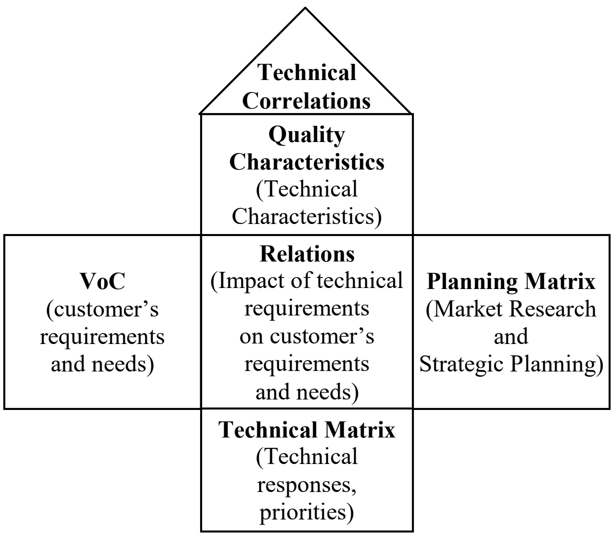
QFD is a process consisting of four stages that provide guidance to participants and facilitate understanding of the process. The steps of the process are listed below (Cohen, 1995);

- Stage 0: Planning;
- Stage 1: Determination of Voice of Customer (VoC);
- Stage 2: Building the House of Quality (HoQ);
- Stage 3: Analysis and Interpretation of Results.

The planning stage (Stage 0) is the process of preparing and setting the ground for the QFD. In Stage 1 (Determination of Voice of Customer), the customer's needs, expectations and requests for the product/service are determined, structured, measured and weighted (Akbaba, 2005). These data constitute the left side of the House of Quality and are known as 'WHATs' in the QFD process (Cohen, 1995).

The creation of the House of Quality (Stage 2) is generally considered the 'QFD Process' (Ficalora & Cohen, 2009). The House of Quality constitutes the basic structure of QFD implementation. This matrix (Table 1) consists of a basic table that compares the customer's requirements and needs (Voice of Customer) with technical characteristics, and a table that forms a roof-like structure on the upper part of matrix compares the technical characteristics with each other (Akbaba, 2005). One of the most useful sequences in creation of the House of Quality and its analysis and interpretation of the results (Stage 3) is i) Determination of customer requirements and needs, ii) Creation and analysis of the planning matrix, iii) Creation of technical (quality) characteristics, iv) Creation and analysis of relational matrix, v) Establishment and analysis of technical correlations, vi) Obtaining and analysing competition criteria, vii) Identification and analysis of targets, vii) Planning the results-based development project.

Table 1. House of Quality Matrix (Cohen, 1995)



After these stages, the final House of Quality is formed. It may not be necessary to implement all the sections described above in the creation of the House of Quality. The QFD team should take into consideration the benefit of the implementation and the time and money to be spent on the process to determine which stages need to be applied (Cohen, 1995).

Fuzzy logic

It is almost impossible to precisely define many events in the real world, while, in traditional set theory, there are sharp distinctions between members or non-members of a set. To solve this confusion and to ensure that events are at a certain level of flexibility, the concept of fuzzy logic was developed by L.A. Zadeh in 1965 (Çelikyılmaz & Türkşen, 2009).

In contrast to a traditional set, a fuzzy set has no crisp boundary. Instead of an approach of 'belonging to set=0' or 'not belonging to set=1', a membership value can be assigned to each object in the interval of [0,1] in a fuzzy set "$\mu_A(x)$" as Equation (1). This smooth transition gives a fuzzy set flexibility in modelling, especially linguistic expressions (Jang, Sun & Mizutani, 1997).

$$\mu_A(x): X \rightarrow [0,1] \tag{1}$$

A fuzzy set described as A, on universe of discourse of X can also be defined as a set of ordered pairs, as in Equation (2) (Çelikyılmaz & Türkşen, 2009).

$$A = \{(x, \mu_A(x)) \mid x \in X\} \tag{2}$$

In fuzzy sets, it is very important to define membership functions. There are some membership functions which are triangular, trapezoidal, and Gaussian. In the literature examined, triangular membership functions (α, β, γ) were commonly used, and membership functions were defined as in Equation (3), also shown as Figure 1. In a triangular membership function, "α" represents the smallest likely value, "β" the most probable value, and "γ" the largest possible value (Akman & Özcan, 2011).

$$\mu_A(x) = \begin{cases} 0 & x < \alpha \\ (x-\alpha)/(\beta-\alpha) & \alpha \le x \le \beta \\ (\gamma-x)/(\gamma-\beta) & \beta \le x \le \gamma \\ 0 & x > \gamma \end{cases} \tag{3}$$

After the membership function is determined and outputs are obtained, the last step of the fuzzy inference system is 'defuzzification' in order to obtain

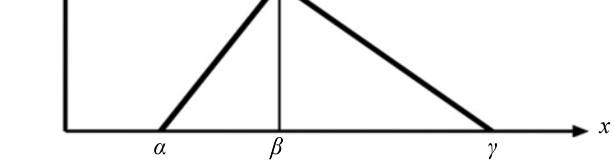


Figure 1. A Triangular membership function

a crisp output from fuzzy inference. There are many methods used for the defuzzification process, such as maxima methods, distribution methods, area methods and miscellaneous methods (Van Leekwijck & Kerre, 1999).

Case study

This paper aims to identify the expectations of customers who receive bunkering services, such as ship owners, charterers, operators or bunker brokers, and evaluate the situation of Istanbul's bunkering services, carried out with the support of the Turkish Bunker Association (TBA). The QFD team carrying out the fuzzy QFD process consisted of a total of 7 members, 4 of whom were members of the Turkish Bunker Association and 3 were academicians. Istanbul was chosen as the region to be implemented in Turkey since most of the bunkering services are supplied in this region. The ports of Piraeus, Valletta, Gibraltar and Singapore were identified as competitors to Istanbul.

Determination of Voice of Customer (VoC)

The first part of the implementation was the determination of the requests and needs of the customers. In this paper, the applied method for customer's requests and needs of the bunkering market was determined through literature research, and a total of 28 criteria were identified from 7 studies directly related to bunkering services (Table 2). The specified criteria were evaluated by the QFD team, and the number of criteria was reduced to 27. The 'Accessibility to port' criterion was integrated with the 'location of port' criterion. These criteria, which were evaluated as secondary level, were structured under the primary level, with more general expressions. Codes were created for each dimension to provide a space advantage while creating the House of Quality. In the following steps of the application, the criteria were expressed in codes.

An online survey method was applied for parties receiving bunkering services to rate the criteria. The survey form collected the participants' profile information, listed the criteria, and asked to what extent the designated bunkering ports met the criteria. It also sought their opinions on the future position of LNG as a fuel. A five-point linguistic scale was used for rating the criteria and assessing the status of bunkering ports. When participants were determined, attention was paid to the fact that the participants worked in the defined regions (Istanbul, Piraeus, Valletta, Gibraltar and Singapore). The survey form was sent to users of bunkering services who agreed to participate. These included buyers (ship owners, charterers or operators) and bunker brokers. Twenty-four appropriate responses were obtained, of which twenty were buyers and four were bunker brokers. The linguistic data obtained were analysed by SPSS 22 (Statistical Package for Social Science) program. According to the analysis results, all values were well above the acceptable limit values and the required reliability ($\alpha > 0.70$) was obtained by Cronbach's alpha. The importance ratings of the criteria had a reliability of 0.868, and the service satisfaction ratings of Istanbul, Piraeus, Valletta, Gibraltar and Singapore had reliability values of 0.860, 0.848, 0.829, 0.890 and 0.849 respectively.

The linguistic variables of VoC criteria were translated into triangular fuzzy numbers as follows ($w_i = w_{i\alpha}, w_{i\beta}, w_{i\gamma}$) and Figure 2:

'1-not important' → (0, 0, 0.25);
'2-less important' → (0, 0.25, 0.50);
'3-so-so' → (0.25, 0.50, 0.75);
'4-important' → (0.50, 0.75, 1.00);
'5-very important' → (0.75, 1.00, 1.00).

The twenty-four appropriate VoC responses were aggregated by utilizing an average operator, as defined by Equation (4). Each weight of VoC with fuzzy numbers was defined as "$w_i = (w_{i\alpha}, w_{i\beta}, w_{i\gamma})$", and the number of approximated data as "d".

$$\text{Weight}_{(\text{VoC})} = \{w_i, \text{ where } i = 1,\ldots,n\}$$

$$w_i = \frac{1}{d} \otimes \left(w_{i1} \otimes w_{i2} \otimes \ldots \otimes w_{id}\right) \tag{4}$$

$$w_i = w_{i\alpha}, w_{i\beta}, w_{i\gamma}$$

To prioritize the importance ratings of VoC, triangular fuzzy numbers [$A = (\alpha, \beta, \gamma)$] were used to carry out the defuzzification process. In this paper, the centroid defuzzification method was used, as in Equation (5), to determine crisp values defined as "Val(A)".

$$\text{Val}(A) = \frac{\alpha + (2 \otimes \beta) + \gamma}{4} \tag{5}$$

The most important factors identified by the customers receiving bunkering services were determined as 'supply waiting time (SWT)', 'bunker quality (BQ)', 'usage and availability of barges (UAB)', 'duration of bunkering operation (DOS)' and 'bunker price and price competitiveness (BPC)' with 0.93, 0.90, 0.89 and 0.87 average scores, respectively. 'Duration of bunkering operation (DOS)' and 'bunker price and price competitiveness (BPC)' criteria had the same average defuzzification score, at 0.87.

Table 2. Voice of Customers Receiving Bunkering Service

Primary Level	Secondary Level (Voice of Customers)	Code	Lam, et al. (2011)	Acosta, Coronado & Cerban (2011)	Chang & Chen (2006)	Wang, Yeo & Ng (2014)	Yao, Ng & Lee (2012)	Boutsikas (2003)	Vilhelmsen, Lusby & Larsen (2013)
Cost	Bunker Price and Price Competitiveness	BPC	✓	✓		✓	✓	✓	✓
	Prices of Complementary Services for Bunker Supply at Anchorage	PCA		✓					
	Prices of Complementary Services for Bunker Supply at Berth (pilotage, mooring, etc.)	PCB		✓					
	Port Tariffs	PT		✓		✓			✓
Service	Usage and Availability of Barges	UAB			✓				
	Availability of Low-sulphur Bunkers	ALB	✓						
	Quality of Bunkering Services (efficiency e.g. pumping rates)	QBS	✓		✓				
	Duration of Supply	DOS			✓				
	Supply Waiting Time	SWT		✓	✓				
	Bunkering Facilities (adequacy and efficacy)	BF	✓		✓	✓			
	Transparency (corruption-free)	TCF	✓						
	Clear and Precise Information About Services	CPI		✓		✓			
	Reliability, Punctuality and Safety of Bunkering Services	RPS	✓			✓			
	Bunker Quality	BQ	✓	✓		✓		✓	
Legal and Political Conditions	Bunkering Rules of Port	BRP				✓			
	Stability of Political Environment	SPE	✓						
	Government Policies (e.g. quality control) and Incentives	GPI	✓						
	Ship Inspection Thoroughness	SIT		✓					
	Customs Strictness	CS		✓					
	Presence of Restrictive Environmental Regulations	PRE		✓		✓			
Geographical and Port Conditions	Weather Conditions of Region	WCR				✓			
	Simplicity of Crew Changes	SCC		✓					
	Location of Port and Closeness the Hinterland	LOP	✓	✓					✓
	Geographical Advantage	GA		✓		✓	✓		✓
	Port Congestion	PC		✓					
	Port Security	PS		✓					
	Anchoring and Docking Availability	ADA		✓					

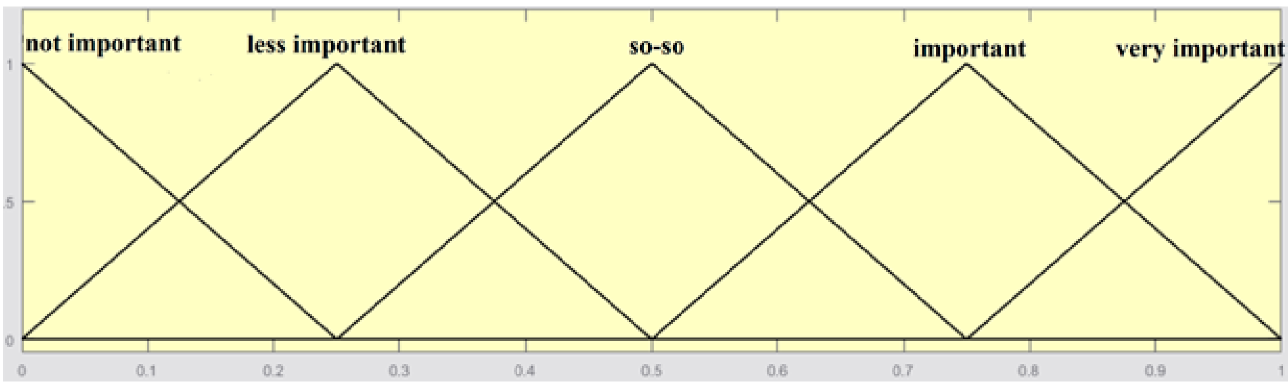


Figure 2. Fuzzy Numbers of VoC

When these results are examined, the most important criteria belong to the 'service' primary level. Also, according to the responses, the criteria which were given the lowest importance ratings were 'ship inspection thoroughness (SIT)', 'presence of restrictive environmental regulations (PRE)', 'simplicity of crew changes (SCC)' and 'customs strictness (CS) with 0.68, 0.69, 0.71 and 0.72 average scores, respectively. Most of these criteria belong to the 'legal and political conditions' primary level.

Building the House of Quality (HoQ)

After the process of determining VoC was completed, the process of building the House of Quality was started. At this stage, first, a planning matrix was established (Table 4). In the planning matrix, the situations of bunkering ports identified as Istanbul and its competitors were obtained by survey form from the parties receiving bunkering. These obtained linguistic values were transformed to fuzzy numbers ($c_i = c_{i\alpha}, c_{i\beta}, c_{i\gamma}$) as below:

'1-poor' → (0, 0, 2.5);
'2-fair' → (0, 2.5, 5);
'3-average' → (2.5, 5, 7.5);
'4-good' → (5, 7.5, 10);
'5-excellent' → (7.5, 10, 10).

'Target' and 'Sales Point' values were set by the QFD team. It is important that the values set are rational. Later, 'Fuzzy Importance Point' numbers were multiplied by the importance ratios of each criterion by 'Progress Ratio' and 'Fuzzy Points of Sales' values. 'Fuzzy Points of Sales' were determined as below. Lastly, the 'Fuzzy Importance Ratings' of the criteria were calculated according to the data obtained:

'no increase in sales' → (0, 0.20, 0.40);
'moderate increase in sales' → (0.30, 0.50, 0.70);
'strong increase in sales' → (0.60, 0.80, 1).

After the planning matrix is created and evaluated, the improvement steps to be carried out in accordance with customer request and needs should be determined. To this end, the QFD team re-evaluated the planning matrix, and technical (quality) characteristics constituting the 'HOWs' part of the House of Quality were determined in line with the VoC. When the technical characteristics were determined, the precautions to be taken by bunker suppliers, stakeholders and the authorities according to the expectations of the customers were carefully evaluated. A total of 12 criteria were determined, which are shown in Table 3.

With the determination of quality characteristics, one of the most important steps of the House of Quality was entered. The relationship degrees of the relation matrix, which were received in words by the QFD team, were determined and converted to fuzzy numbers as below ($r_i = r_{i\alpha}, r_{i\beta}, r_{i\gamma}$):

'no relation' → (0, 0, 1); 'weak relation' → (0, 2, 4); 'moderate relation' → (2, 5, 8); 'strong relation' → (7, 10, 10).

Table 3. Technical Characteristics Determined for Bunkering Services

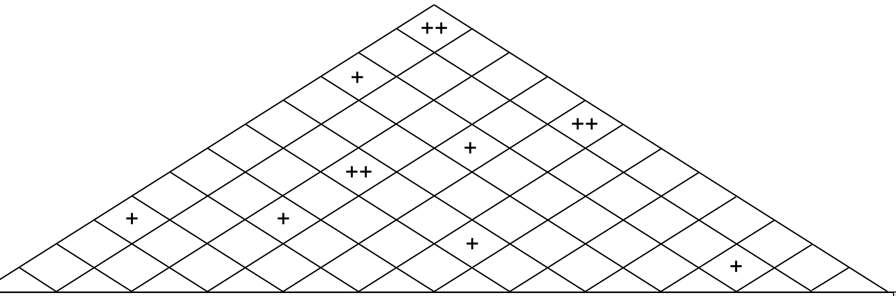
	Technical Characteristics	
1	Increasing storage facilities and capacities	ISC
2	Allowing fuel blends (blending)	AFB
3	Arrangement of customs working hours in accordance with the structure of industry	CWH
4	Increasing the number of supply zones (especially for transit vessels)	ISZ
5	Ending collection of extra charges for bunkering operations (by ports)	LEC
6	Removal of the obligation to open the bunkering declaration on board	RBD
7	Exemption from local taxes and fees on transit sales	LTF
8	The creation of a structure that can provide 24/7 bunkering	CSP
9	Developing an effective and productive marketing approach	EPM
10	Increasing the number and capacity of bunker barges	NCB
11	Widespread use of mass flow meters (MFM) in bunkering operations	MFM
12	Increasing importance of bunkering in port infrastructure and management thinking (bunker port concept)	BPC

With the quantification of the correlation matrix, the 'Technical Significance (Importance) Level' of each quality characteristic become calculable. 'Fuzzy Technical Significance Level' is calculated by summing the product of 'Fuzzy Importance Rating' and 'Fuzzy Relationship Degree' of each criterion's fuzzy numbers at the end of the column, as seen below Equation (6). Technical Significance Scores (TS) obtained from the study are also shown in Table 4. As in the aforementioned, "w_i" presents weight of VoC, and "r_i" presents relationship degrees.

$$\mathrm{TS} = \sum_{i=1}^{n} \left[\left(w_i \otimes r_{ij} \right) \right], \quad i = 1, \dots, n, \quad j = 1, \dots m \qquad (6)$$

After obtaining technical significance levels and normalized values, the quality characteristics could be defuzzified and prioritized. Prioritized technical characteristics for bunkering services were found as 'Increasing storage facilities and capacities (ISC)', 'The creation of a structure that can provide 24/7 bunker supply (CSP)', 'Increasing importance of bunkering in port infrastructure and management

Table 4. House of Quality for Bunkering Services



Voice of Customer		Fuzzy Importance Ratings			ISC			AFB			CWH			ISZ			LEC			RBD			LTF			CSP			EPM			NCB			MFM			BPC		
		α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ
Cost	BPC	0.32	0.73	1.00	7	10	10	7	10	10	2	5	8	2	5	8	7	10	10	0	2	4	7	10	10	2	5	8	2	5	8	2	5	8	2	5	8	2	5	8
	PCA	0.22	0.52	0.87	0	2	4	0	2	4	2	5	8	7	10	10	2	5	8	0	0	1	2	5	8	2	5	8	2	5	8	0	2	4	0	0	1	0	2	4
	PCB	0.22	0.52	0.85	0	2	4	0	2	4	2	5	8	0	0	1	7	10	10	0	0	1	2	5	8	2	5	8	0	2	4	0	2	4	0	0	1	0	2	4
	PT	0.00	0.23	0.53	0	0	1	0	0	1	2	5	8	0	0	1	7	10	10	0	0	1	0	2	4	0	2	4	0	2	4	0	2	4	0	0	1	7	10	10
Service	UAB	0.27	0.62	0.93	7	10	10	0	2	4	2	5	8	7	10	10	0	2	4	2	5	8	2	5	8	7	10	10	2	5	8	7	10	10	0	2	4	2	5	8
	ALB	0.25	0.58	0.89	7	10	10	7	10	10	0	0	1	0	2	4	0	0	1	0	0	1	0	0	1	0	2	4	0	2	4	0	2	4	0	0	1	2	5	8
	QBS	0.25	0.57	0.90	7	10	10	7	10	10	7	10	10	7	10	10	7	10	10	2	5	8	0	2	4	7	10	10	7	10	10	7	10	10	7	10	10	7	10	10
	DOS	0.23	0.53	0.80	7	10	10	2	5	8	7	10	10	2	5	8	0	2	4	2	5	8	0	0	1	7	10	10	0	2	4	7	10	10	7	10	10	2	5	8
	SWT	0.28	0.63	0.89	7	10	10	2	5	8	7	10	10	7	10	10	2	5	8	2	5	8	0	0	1	7	10	10	0	2	4	7	10	10	7	10	10	2	5	8
	BF	0.00	0.17	0.40	7	10	10	2	5	8	0	0	1	0	0	1	0	0	1	0	0	1	2	5	8	2	5	8	0	2	4	7	10	10	0	2	4	7	10	10
	TCF	0.00	0.20	0.44	0	2	4	0	2	4	0	0	1	0	2	4	0	0	1	0	2	4	0	2	4	0	2	4	7	10	10	0	2	4	7	10	10	0	0	1
	CPI	0.00	0.20	0.47	0	0	1	2	5	8	0	2	4	0	0	1	0	2	4	0	2	4	0	2	4	0	2	4	7	10	10	0	2	4	7	10	10	0	0	1
	RPS	0.00	0.22	0.48	7	10	10	0	0	1	7	10	10	7	10	10	0	0	1	2	5	8	0	0	1	0	2	4	0	2	4	7	10	10	7	10	10	2	5	8
	BQ	0.47	0.86	1.00	2	5	8	7	10	10	0	0	1	0	0	1	0	0	1	0	0	1	2	5	8	0	0	1	0	2	4	0	2	4	0	0	1	0	2	4
Legal and political Conditions	BRP	0.22	0.54	0.89	0	2	4	0	0	1	0	2	4	0	2	4	0	0	1	2	5	8	0	0	1	2	5	8	0	0	1	0	2	4	0	2	4	2	5	8
	SPE	0.26	0.62	1.00	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
	GPI	0.44	0.85	1.00	0	2	4	2	5	8	2	5	8	0	0	1	0	0	1	2	5	8	2	5	8	2	5	8	0	0	1	0	0	1	0	0	1	0	0	1
	SIT	0.00	0.17	0.45	0	0	1	0	0	1	0	2	4	0	0	1	0	0	1	2	5	8	0	0	1	0	2	4	0	0	1	0	0	1	0	0	1	0	0	1
	CS	0.41	0.81	1.00	0	0	1	0	0	1	0	2	4	0	0	1	0	0	1	2	5	8	0	2	4	0	2	4	0	0	1	0	0	1	0	0	1	0	0	1
	PRE	0.00	0.16	0.41	0	0	1	2	5	8	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	2	4
Geographical and Port Conditions	WCR	0.00	0.17	0.39	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1
	SCC	0.00	0.14	0.37	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	2	4
	LOP	0.00	0.18	0.40	0	2	4	0	0	1	0	0	1	0	0	1	0	2	4	0	0	1	0	0	1	0	2	4	0	0	1	0	0	1	0	0	1	7	10	10
	GA	0.22	0.52	0.82	0	2	4	0	0	1	0	0	1	0	0	1	0	2	4	0	0	1	0	2	4	0	2	4	0	0	1	0	2	4	0	0	1	7	10	10
	PC	0.21	0.49	0.79	0	0	1	0	0	1	0	0	1	2	5	8	0	0	1	0	2	4	0	2	4	0	0	1	0	2	4	0	0	1	0	0	1	2	5	8
	PS	0.00	0.18	0.41	0	0	1	0	0	1	0	0	1	0	2	4	0	0	1	0	0	1	0	2	4	0	2	4	0	0	1	0	0	1	0	0	1	0	2	4
	ADA	0.00	0.19	0.44	0	0	1	0	0	1	2	5	8	0	0	1	2	5	8	0	2	4	0	2	4	0	2	4	0	2	4	0	2	4	0	0	1	2	5	8
FUZZY TECHNIC IMPORTANCE LEVEL					12.17	51.50	98.33	10.95	43.83	90.04	8.25	41.25	94.27	8.65	37.41	81.57	6.47	31.29	73.98	4.21	28.34	79.71	5.47	31.73	80.61	10.07	47.11	104.63	3.34	27.89	75.99	7.86	39.82	87.09	5.95	29.79	68.37	6.86	44.17	107.80
DEFFUZIFICATION TECHNIC IMPORTANCE LEVEL					53.38			47.16			46.26			41.26			35.76			35.15			37.39			52.23			33.78			43.65			33.47			50.75		
NORMALISED					11.62			10.26			10.07			8.98			7.78			7.65			8.14			11.37			7.35			9.50			7.29			11.04		

Voice of Customer	Importance Ratings			Istanbul			Piraeus			Valletta			Gibraltar			Singapore			Target	Progress Ratio	Point of Sales		
	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ	α	β	γ			α	β	γ
BPC	0.67	0.92	0.99	2.40	4.79	7.19	3.02	5.42	7.81	3.65	6.04	8.33	4.17	6.67	8.85	4.79	7.29	9.38	7.60	1.59	0.30	0.50	0.70
PCA	0.58	0.83	1.00	3.65	6.15	8.44	3.33	5.83	8.23	3.44	5.94	8.33	3.54	6.04	8.54	5.00	7.50	9.17	7.60	1.25	0.30	0.50	0.70
PCB	0.58	0.83	0.98	3.65	6.15	8.54	3.33	5.83	8.23	3.33	5.83	8.13	2.92	5.42	7.92	4.58	7.08	9.06	7.60	1.24	0.30	0.50	0.70
PT	0.60	0.85	0.97	0.40	6.46	8.75	3.23	5.73	8.13	3.54	5.94	8.33	3.13	5.63	8.02	4.90	7.40	9.48	7.50	1.36	0.00	0.20	0.40
UAB	0.69	0.94	1.00	3.50	6.04	8.54	3.96	6.46	8.96	2.92	5.42	7.92	4.69	7.19	9.27	5.10	7.60	9.48	8.00	1.33	0.30	0.50	0.70
ALB	0.66	0.91	0.99	4.00	6.25	8.33	4.06	6.56	8.85	4.38	6.77	8.96	5.10	7.50	9.27	5.21	7.60	9.17	8.00	1.29	0.30	0.50	0.70
QBS	0.63	0.88	0.98	4.00	6.46	8.96	3.23	5.73	8.23	2.92	5.31	7.60	4.06	6.56	8.85	4.48	6.88	9.17	8.50	1.31	0.30	0.50	0.70
DOS	0.67	0.92	9.27	4.50	6.98	9.27	3.85	6.35	8.85	2.81	5.31	7.81	3.65	6.15	8.33	4.17	6.67	8.96	8.00	1.15	0.30	0.50	0.70
SWT	0.74	0.99	1.00	3.85	6.35	8.65	2.92	5.42	7.92	2.40	4.69	6.98	3.33	4.73	8.02	4.17	6.67	8.65	8.00	1.27	0.30	0.50	0.70
BF	0.59	0.84	0.99	4.48	6.98	9.06	3.65	6.15	8.54	3.13	5.52	8.02	4.58	7.08	9.06	4.90	7.40	9.48	7.00	1.02	0.00	0.20	0.40
TCF	0.58	0.83	0.95	4.48	6.88	9.06	2.50	4.90	7.29	2.81	5.21	7.40	3.65	6.04	8.33	3.13	5.52	7.81	8.00	1.17	0.00	0.20	0.40
CPI	0.59	0.84	0.99	4.38	6.88	8.96	3.13	5.52	8.02	3.23	5.52	7.81	3.96	6.46	8.85	4.27	6.77	9.06	8.00	1.18	0.00	0.20	0.40
RPS	0.66	0.91	0.99	4.17	6.67	8.65	2.60	5.00	7.50	2.50	4.69	7.08	4.06	6.56	8.85	3.75	6.25	8.65	8.00	1.22	0.00	0.20	0.40
BQ	0.70	0.95	1.00	4.48	6.88	8.96	1.67	3.85	6.25	2.19	4.27	6.67	3.54	5.73	7.92	2.60	5.00	7.29	7.70	1.13	0.60	0.80	1.00
BRP	0.56	0.81	0.96	3.23	5.73	8.13	3.54	6.04	8.44	4.17	6.67	9.06	4.27	6.77	9.17	4.69	7.19	9.38	7.60	1.33	0.30	0.50	0.70
SPE	0.55	0.80	0.95	2.40	4.69	7.19	3.13	5.63	8.13	3.96	6.46	8.96	4.17	6.67	9.06	4.27	6.77	9.06	7.30	1.54	0.30	0.50	0.70
GPI	0.55	0.79	0.95	3.13	5.31	7.81	2.92	5.42	7.81	3.44	5.83	8.23	4.48	6.88	9.17	4.27	6.77	8.96	7.20	1.34	0.60	0.80	1.00
SIT	0.45	0.69	0.90	3.02	5.52	8.02	3.02	5.52	8.02	2.92	5.42	7.92	3.23	5.73	8.13	3.75	6.25	8.54	7.00	1.27	0.00	0.20	0.40
CS	0.49	0.73	0.92	3.13	5.31	7.60	3.44	5.83	8.23	3.75	6.15	8.44	4.06	6.46	8.75	4.90	7.29	9.48	7.40	1.39	0.60	0.80	1.00
PRE	0.46	0.70	0.90	3.65	6.15	8.54	3.44	5.94	8.33	3.44	5.94	8.33	3.65	6.15	8.65	4.17	6.67	9.06	7.00	1.14	0.00	0.20	0.40
WCR	0.60	0.85	0.97	3.54	6.04	8.44	3.96	6.46	8.96	1.56	3.33	5.83	2.92	5.31	7.71	5.10	7.60	9.38	6.02	1.00	0.00	0.20	0.40
SCC	0.48	0.72	0.92	4.79	7.29	9.06	2.81	5.10	7.60	2.60	4.90	7.29	3.02	5.52	7.92	5.21	7.71	9.17	7.11	1.00	0.00	0.20	0.40
LOP	0.64	0.89	0.99	4.38	6.88	9.27	2.60	5.10	7.50	4.06	6.56	8.75	4.90	7.40	9.27	5.52	8.02	9.58	6.85	1.00	0.00	0.20	0.40
GA	0.63	0.88	0.99	4.38	6.88	8.96	2.50	5.00	7.50	3.96	6.35	8.54	5.52	8.02	9.38	6.56	9.06	9.90	8.00	1.18	0.30	0.50	0.70
PC	0.59	0.84	0.97	3.54	6.04	8.33	3.54	6.04	8.44	2.81	5.21	7.71	2.71	5.00	7.29	2.81	5.21	7.71	7.00	1.17	0.30	0.50	0.70
PS	0.55	0.80	0.91	5.21	7.71	9.58	4.79	7.29	9.38	4.27	6.67	8.85	4.90	7.40	9.48	4.48	6.98	9.17	8.50	1.13	0.00	0.20	0.40
ADA	0.58	0.83	0.97	4.27	6.77	8.96	3.23	5.73	8.02	2.92	5.31	7.71	3.75	6.04	8.23	5.00	7.50	9.27	7.60	1.14	0.00	0.20	0.40

thinking (BPC)', and 'Increasing the number and capacity of bunker barges (NCB)' with 53.38 (11.62%), 52.23 (11.37%), and 50.75 (11.04%) scores and normalised values, respectively. As seen in these results, the criteria having the highest scores are very close in values.

The final stage in creating the House of Quality is the technical correlation. Relationships between the technical characteristics were evaluated by the QFD team and the obtained data are shown at the top of Table 4. There are some weak (+) and strong (++) positive relations between technical characteristics, while weak (−) or strong (−−) negative relations are not seen. Weak positive relations are 'ISC-ISZ', 'CWH-RBD', 'RBD-CSP', 'ISZ-NCB', 'NCB-MFM', 'NCB-ISC'. Strong positive relations are 'CWH-CSP', 'ISC-BPC' and 'LEC-BPC'. As mentioned before, this matrix is the least used matrix in the QFD process. These correlations mean that if 'ISC' is improved, 'ISZ' may be improved slightly positively. The other correlations are interpreted in the same way.

The resulting matrices eventually became the final House of Quality. The design of the House of Quality was completed by combining the customer requirements and the importance ratings, which were the starting points of the QFD process, the planning matrix, the technical characteristics, the relationship matrix, and the technical correlation matrix. The resulting House of Quality created for bunkering services is shown in Table 4.

The 24 appropriate responses obtained were also analysed with the classical QFD approach. When the results were compared, the ranking of VoC criteria was the same, while there were minor differences in the ranking of technical characteristics. The ranking of prioritized technical characteristics in Fuzzy QFD process was as 'ISC', 'CSP' and 'BPC' although the ranking of the classic QFD process was determined as 'ISC', 'BPC' and 'CSP'. However, 'ISC' was identified as the most important technical characteristic in both the classic QFD process, and fuzzy QFD.

The participants were also asked about their views on LNG as an alternative fuel for the future. According to the responses, 52.4% of participants think that LNG could replace conventional fuels, while 47.6% state that conventional fuels will maintain dominance of the maritime industry.

Conclusions

In this paper, the aim is to determine the situation of Istanbul, which is the most important bunker supply region of Turkey, in terms of service buyers, and to determine the steps that will increase its competitive power against its competitors, using the Fuzzy QFD method.

When the obtained data were examined, it was seen that customers receiving bunkering services gave high importance to the criteria of 'supply waiting time', 'bunker quality', 'usage and availability of barges', 'fuel price and price competition' and 'duration of supply operation'. These findings are parallel with those found in the literature. 'Bunker quality', 'bunker price and price competition', 'custom strictness' and 'government policies and incentives' were found to be measures with the highest percentage significance ratings in the planning matrix, in that order of importance. It is seen that the criteria of 'bunker quality' and 'bunker price and price competitiveness' are common grounds for both bunker customers and suppliers. Acosta, Coronado & Cerban (2011) pointed out that these criteria were very important for customers when choosing a bunkering port. Transparency did not have a high score in this paper, while Lam et al. (2011) found it one of the most important factors. It is thought that the reason for this result is the effect of constantly developing technology, such as mass flow meters, and regulations on bunkering procedures.

The most important steps to be taken in order to improve bunker services of Istanbul were found to be 'Increasing storage facilities and capacities', 'The creation of a structure that can provide 24/7 bunker supply' and 'Increasing importance of bunkering in port infrastructure and management thinking (bunker port concept)'. To increase storage facilities and capacities may provide advantages to suppliers in terms of both achieving competitive prices in bunker and product diversity. Moreover, it can be predicted that having an adequate level of storage can shorten the supply waiting period. The creation of a structure that can provide 24/7 bunker supply is expected to prevent the problems that may be encountered in night supply operations and customs-related processes in Turkey. Bunker port concept is also directly related to storage facilities. A strong positive correlation was also found between the two measures in the correlation matrix of the improvement steps. Especially, the presence of bunkering facilities built in ports in strategic regions is thought to be able to improve both waiting times of supply and cost reductions for the supplier. The reputation of a port as a bunkering port increases its competitive advantage and market share, as stated by Acosta, Coronado & Cerban (2011) and Lam et al. (2011) for Gibraltar and Singapore, respectively. If these steps are taken, Istanbul can be a bunkering hub and more competitive against other ports.

52.4% of participants in the survey responded that LNG could replace conventional fuels. The remaining 47.6% commented that there would be no such change in the future. The reasons for not meeting a common point in the answers to this question are that the infrastructure required for the LNG procurement operation is at a start-up phase in the world, that it is costly for vessels to pass through LNG-fuelled machines and that they face bunker supply problems due to low infrastructure capacity.

The findings cam be a guide to ship fuel suppliers, especially in Turkey, and may help them to increase their fuel sales volume. Increasing Turkey's share by turning its geographical potential to advantage is a very important matter for both the sector and the country's economy.

The limitations encountered in research were the inability to include stakeholders such as port authorities and state authorities. Because of the process and time constraints of the application, it was not possible for these stakeholders to be involved in the research.

It is suggested that the research will need to be developed and revised in the future for reasons such as continual revision of emission control areas and regulations, especially the consequences of the global 0.5% sulphur emission restriction, which is expected to come into force in 2020. A comprehensive study, including the bunkering sector and its stakeholders, is expected to give positive results for the sector. In addition, highly useful data can be obtained in terms of literature and industry by studies of bunkering operation processes and risk assessments.

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