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An integrated fuzzy QFD model proposal on routing of shipping investment decisions in crude oil tanker market

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ABSTRACT

Monitoring the market has crucial roles for executing the shipping investment decisions in maritime transportation industry. The high level of managerial effort requires bringing market tendencies with the up-to-date data over dynamic parameters. This paper extends the Quality Function Deployment (QFD) principles towards shipping investment process via the originally proposed Ship of Quality (SoQ) framework. Furthermore, the Fuzzy Analytic Hierarchy Process (FAHP) and Fuzzy Axiomatic Design (FAD) algorithms are integrated into the SoQ frame in order to involve quantitative outcomes into the shipping investment decisions. The SoQ is performed over a set of periodical data and recent trends of the principal crude oil tanker markets such as Very Large Crude Oil Carriers (VLCCs), Suezmaxes, and Aframaxes in order to ensure the illustrative results. As an effective investment tool, the proposed SoQ model is expected to provide invaluable decision aid for the relevant shipping executives.

1. Brief introduction on shipping investment

Monitoring and predicting dynamic parameters of the maritime transportation industry such as freight rates, ship sale and purchase prices, new building trends, bunker prices, and scrapping rates (Tsolakis, Cridland, & Haralambides, 2003) have enforced the executives in shipping business. Integration of innovative technologies (Lee et al., 2006), effective communication (Jenssen & Randoy, 2006), and improving managerial skills (Celik & Er, 2006a; Hork, 2004; Panayides, 2006) are the key aspects to ensure customer satisfaction in the market. Especially, the investment decision and timing (Alizadeh & Nomikos, 2007) are the potential issues to manage the market competitiveness in maritime transportation industry. The investment decisions in shipping require assessing the high level of up-to-date information towards the technical and commercial variables of maritime transportation market. At this point, diversity of the different market options (*i.e. bulk carrier market, crude oil market, container market, gas & chemical markets*) increases the complexity of the shipping investment problem. Moreover, additional assessments need to be performed over critical issues such as return on investment (Cullinane, 1995), catastrophic risks (Celik & Er, 2006b), and oil crises (Bergin & Glick, 2007) to ensure the feasibility of the shipping enterprises. However, the customer satisfaction levels in the market can systematically be linked to the route of new investment decisions. This idea reduces the additional efforts in shipping investment decisions and it provides the reflection of the overall market trends for the relevant decision-makers. In maritime transportation industry, the charterers are recognized as the potential customers of the ship management companies who operate the merchant fleets on behalf of the ship owners. In this way, the ship owners and the relevant managers as potential decision-makers can shift the route of shipping investments with respect to the recent tendencies of charterers and daily statistics over the market indicators.

This paper focuses on structuring a decision aid mechanism on the basis of Quality Function Deployment (QFD) model under fuzzy environment in order to route investment decisions with respect to the customer satisfaction level of shipping charterers in crude oil tanker markets. It aims at measuring charterers' tendencies to route the investment decisions of global ship owners. The research methodology ensures embedding the recent statistical data of different markets (*i.e. Very Large Crude Oil Carriers (VLCCs), Suezmaxes, and Aframaxes*) into the QFD-based decision-aid mechanism. On the other hand, the Fuzzy Analytic Hierarchy Process (FAHP) algorithm derives the relative importance of performance characteristics of each market while the Fuzzy Axiomatic Design (FAD) ensures the selection of the suitable market alternative.

The remaining parts of this paper are organized as follows: in Section 2, the theoretical background of the research methodology

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which also includes a literature review on the QFD applications through measuring customer satisfaction is described . In Section 3, the extension of the Fuzzy QFD model to shipping investment decisions is illustrated towards crude oil tanker markets via using the recent statistical data. Concluding remarks and proposals for further research are expressed within the last section of this paper.

2. Research methodology

The research methodology of this paper is established on the basis of OFD principle. The house of quality (HoQ) is modified to ensure the compliance of the proposed mechanism with the shipping investment decisions. Furthermore, the solution is performed based on decision-making algorithms under fuzzy environment. This section enables the required information through the methodological concept of this research.

2.1. Background of QFD

Historically, the concept of QFD was initiated by *Akao* in 1966, expanded in 1969, and published as a system prototype in 1972. Then, the application of idea was widespread towards the individual organizations (*i.e. Mitsubishi Heavy Industry, Toyota Auto Body, Sawada Auto Body etc.*) in different industrial branches (Velle, Cox, & Moran, 1997). In the last decade, there have been several modifications performed over the initial structure and principles of QFD.

The QFD is a technique for product or service development, brand marketing, and product management. The primary purpose of the QFD approach is to help planners in order to focus on the characteristics of the products or services from the viewpoints of market segments. Furthermore, it is a concept and mechanism for translating the voice of the customers through the various stages of product planning, engineering, manufacturing into product. Systematically, each translation uses a chart on the basis of HoQ frame. The HoQ typically contains information on "what to do" (performance characteristic), "how to do it" (engineering characteristics), and the integration of this information and the relevant benchmarking data (Kim, Jang, Lee, & Cho, 2000). The traditional QFD model is based on the paradigm of designing and manufacturing physical objects related to the system hardware. However, QFD has been extended beyond its initial concept.

2.2. A brief review on QFD applications

The QFD model has several applications in various eras. A wide range of literature review over QFD applications was already represented by Chan and Wu (2002) and Xie et al. (2003). The practical applications of the QFD approach have been forwarded to the key topics and fields as follows: automotive (De Vera, Glenon, Kenny, Khan, & Mayer, 1988; Tsuda, 1997), construction (Abdul-Rahman, Kwan, & Woods, 1999; Armacost, Componation, Mullunes, & Swart, 1994; Dikmen, Birgonul, & Kiziltas, 2005; Mallon & Mulligan, 1993), education (Bier & Cornesky, 2001; Chen & Bullington, 1993; Ermer, 1995; Franceschini & Terzago, 1998; Hwarn & Teo, 2001; Lam & Zhao, 1998; Pitman, Motwani, Kumar, & Cheng, 1995; Shieu-ming, 2004), electronics (Burrows, 1991; Herzwurm & Schockert, 2003; Kwong, Chen, Bai, & Chan, 2007; Liner, Loredo, Gitlow, & Einspruch, 1997; Tan & Neo, 2002), food industry (Bech, Hansen, & Wienberg, 1997; Benner, Linnemann, Jongen, & Folstar, 2003; Charteris, 1993; Costa, Dekker, & Jongen, 2000; Viaene & Januszewska, 1999), healthcare (Foester, 2001; Hauser, 1993; Jeong & Oh, 1998; Moores, 2006; Radharamanan & Godoy, 1996), marketing (Aungst, Barton, & Wilson, 2003; Lu & Kuei, 1995; Lu, Madu, Kuei, & Wikonur, 1994; Mohr-Hackson, 1996; Vairaktarakis, 1999), service (Arai & Shimomura, 2005; Denton, 1990; Dube, Johnson, & Renaghan, 1999; Ermer & Kniper, 1998; Ghobadian & Terry, 1965; Graessel & Zeidler, 1993; Pun, Chin, & Lau, 2000; Selen & Schepers, 2001), and software (Barnett & Raja, 1995; Chakraborty & Dey, 2007; Erikkson & McFadden, 1993; Elboushi & Sherif, 1997; Haag, Raja, & Schkade, 1996; Karlsson, 1997; Pai, 2002; Trappey, Trappey, & Hwang, 1996; Yoshizawa, Akao, Ono, & Shingo, 1993). The outcomes of the QFD-based models have ensured the required feedbacks to the relevant organizations in different industries. Besides the well-structured implementations, the QFD methodology has been integrated with other traditional methods in order to design hybrid assessment system. This paper has attempted to establish a decision-aid mechanism towards the execution of shipping investment decisions based on customer satisfaction levels in different markets.

2.3. Establishing of links to customer satisfaction & investment planning

In a broad sense, the QFD method consists of three main steps: (1) identifying the customer needs as voice of the customer (VoC), (2) determining the engineering characteristics of products or services that meet VoC, (3) setting development targets and test methods for the products or services. However, this paper eagerly motivates to establish a systematic decision mechanism over shipping investment by measuring the customer tendencies in the maritime market. Hence, the literature review for this study has shifted towards the QFD applications in measuring of the customer satisfaction. As an illustrative case from the literature, Kim et al. (2000) proposed a methodology based on HoQ to construct a decision path for Information Technology (IT) investments. Partovi (2007) proposed a QFD model with AHP integration that deals with the selection of adequate manufacturing system by concerning the needs the of customers in the target market on the basis of integrated QFD model. However, the outcomes of our paper act as a decision aid for new investments in market level instead of redesigning the existing organizational process. It is another phenomenon to assess a shareholder value as a guiding principle in customer relationships of firms (Stahl, Matzler, & Hinterhuber, 2003). Hence, this study settled the market indicators in the proposed QFD framework to analytically measure the charterers' perceptions as one of the potential shareholders of ship owners in maritime transportation industry.

In spite of the limited extensions of QFD to investment planning in the literature, many of the previous studies also directly focused on exploring customer satisfaction in order to manage the effectiveness in product development (Kumar & Midha, 2001; Pullman, Moore, & Wardell, 2002), environmental protection (Halog, Schultmann, & Rentz, 2001; Thurston, Lloyd, & Wallace, 1994), training curriculum redesign (Chou, 2004; Lee & Lo, 2003; Motwani, Kumar, & Mohamed, 1996), system integration (Shamsuddin, 2004), and so on. The remaining parts of this study eagerly focus on combining the investment decisions with the market-based data related to the customer satisfaction levels based on QFD model that is also supported with the integrated solution algorithms.

2.4. Integrated design & solution algorithms for QFD

2.4.1. Review on current approaches

Although QFD has been proposed and put in use for several decades, it is still in its developmental stage (Xie, Tan, & Goh, 2003). The structure of the QFD models was strengthen by integrated different traditional techniques and approaches such as Total Quality Management (TQM), Theory of solving inventive problems (TRIZ), Failure Mode and Effects Analysis (FMEA), Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), Technique for Order

Preference by Similarity to Ideal Solution (TOPSIS), and artificial intelligence. (Cristiano, Liker, & White, 2000; Delano, Parnell, Smith, & Vance, 2000; Griffin, 1992; Masui, Sakao, Kobayashi, & Inaba, 2003; Matzler & Hinterhuber, 1998; Price, 1995; Tottie & Lager, 1995; Yamashina, Ito, & Kawada, 2002; Karsak, 2004; Buyukozkan & Feyzioglu, 2005; Chen, Fung, & Tang, 2006; Kahraman, Ertay, & Buyukozkan, 2006; Lin, Wang, Chen, & Chang, 2008). As a critical contribution to the literature, this study presented an integrated model using FAHP and FAD on the basis of QFD framework in order to extend the HoQ principles to investment planning. The extension of HoQ towards shipping investment process which is the so-called Ship of Quality (SoQ) is originally proposed in this paper (see Fig. 4). The integrated algorithms of SoQ are structured in detail in further sections. The main aim of the proposed modifications is to route the investment decisions via measuring the charterers' perception in different tanker shipping markets. The performance of the proposed SoQ model over the recent statistical data of the different investment options in global crude oil tanker market is described in further section.

2.4.2. Proposed mechanism on shipping investment decisions: ship of quality (SoQ)

The fundamental of the proposed SoQ model is supported with the FAHP and FAD methodologies. The integrated algorithm is illustrated in Fig. 1. The initial phase of the proposed methodology defines the performance characteristics (PCs) and technical characteristics (TCs), respectively. At the end of the maritime industry-based survey, the following PCs are defined: on-time delivery in service period (y_1), draft restriction problems (y_2), off-hire average (y_3), geographical advantages in bunkering operations (y_4), innovative effects of marine technology (y_5), consequence effects of operational catastrophes (y_6), bureaucracy level in port and terminal operations (y_7), advantages in the range of second-hand prices (y_8), trends of demolition sales (y_9), delivery performance of shipbuilding sector (y_{10}). On the other hand, the TCs consist of periodically monitored market statistics such as average spot earnings (x_1), total number of sales (x_2), new building prices (x_3), available number of ships (x_4), and tonnage of shipping fleet (x_5). Since the PCs and TCs are two major components of the SoQ, the relevant decision-makers should consistently identify the latent links between them. In the proposed model, towards shipping investment decisions, managing of the effective correlations provides an invaluable decision support for monitoring the market.

In the next phase (Phase A), the FAHP methodology on Buckley's (1985) algorithm calculates the relative importance of PCs. Buckley (1985) extended traditional AHP method to incorporate fuzzy comparison ratios a_{ij}. In Buckley's approach, geometric mean method is used to derive fuzzy weights and performance scores. The FAHP is preferred due to its simple nature in order to extend the fuzzy case and it guarantees a unique solution to the reciprocal comparison matrix. The procedure can be summarized as follows (Chen & Hwang, 1992):

$$\tilde{C} = \begin{vmatrix} 1 & \tilde{c}_{12} & \dots & \tilde{c}_{1n} \\ \tilde{c}_{21} & 1 & \dots & \tilde{c}_{2n} \\ \vdots & :::: & \vdots & \\ \tilde{c}_{i1} & \tilde{c}_{i2} & \dots & \tilde{c}_{ij} \\ \vdots & :::: & \vdots & \\ \tilde{c}_{m1} & \tilde{c}_{m2} & \dots & 1 \end{vmatrix}, \tag{1}$$

where $\tilde{C}$ is a pairwise comparison matrix, m and n are the number of alternatives and criteria, i indicates ith, alternative, and j indicates jth criterion, respectively. The linguistic scale, given in Table 1 (Hsieh, Lu, & Tzeng, 2004), can be used for triangular fuzzy numbers in Eq. (1). So, the linguistic terms are transformed into fuzzy numbers by the following equation

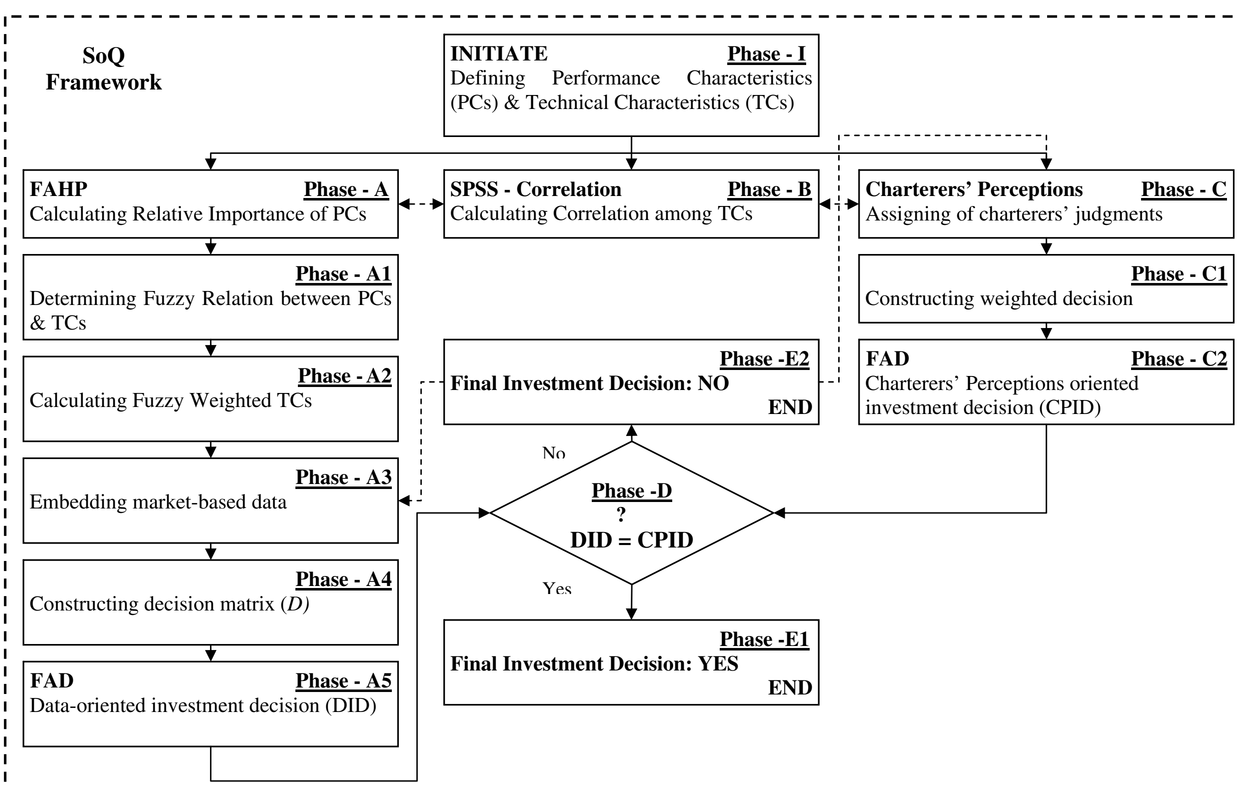

Fig. 1. Integrated fuzzy algorithm on SoQ framework.

Table 1
Linguistic scale for weight matrix

Linguistic scales	Abbreviations	Scale of triangular fuzzy number
Equally important	(Eq)	(1,1,3)
Weakly important	(Wk)	(1,3,5)
Essentially important	(Es)	(3,5,7)
Very strongly important	(Vs)	(5,7,9)
Absolutely important	(Ab)	(7,9,9)

$$\tilde{c}_{ij} = \begin{cases} i > j, & (1,1,3),(1,3,5),(3,5,7),(5,7,9),(7,9,9), \\ i = j, & 1, \\ i < j, & (1,1,3)^{-1},(1,3,5)^{-1},(3,5,7)^{-1},(5,7,9)^{-1},(7,9,9)^{-1}. \end{cases} \tag{2}$$

Then, the fuzzy weight matrix is calculated by Buckley's Method as follows:

$$\tilde{r}_i = (\tilde{c}_{i1} \otimes \tilde{c}_{i2} \otimes \cdots \otimes \tilde{c}_{in})^{1/n}, \tag{3}$$

$$\tilde{w}_{PCi} = \tilde{r}_i \otimes (\tilde{r}_1 + \tilde{r}_2 + \cdots + \tilde{r}_n)^{-1}, \tag{4}$$

where $\tilde{c}_{in}$ is the fuzzy comparison value of criterion i with respect to criterion n, $\tilde{r}_i$ is the geometric mean of fuzzy comparison values of criterion i with respect to each criterion.

Within Phase B, correlation among the TCs is calculated via Statistical Package for the Social Sciences (SPSS) programme. Parallel to this stage, charterers' perceptions are measured via using fuzzy preferences in Phase C. Then, the relations between PCs and TCs are identified by the maritime experts in Phase A1. A group of maritime experts and industry professionals were involved in this stage. Furthermore, the relation is identified by linguistic terms such as very weak (VW), weak (W), moderate (M), strong (S), and very strong (VS). Fig. 2 illustrates the numerical values of the linguistic terms. In Phase A2, based on the expert judgments, the importance values of the TCs are computed via

$$\tilde{w}_{TCj} = \tilde{r}_{TC1j} \otimes \tilde{w}_{PC1} \oplus \tilde{r}_{TC2j} \otimes \tilde{w}_{PC2} \oplus \cdots \oplus \tilde{r}_{TCnj} \otimes \tilde{w}_{PCm}, \tag{5}$$

where $\tilde{r}_{TCij}$ is the relation values between TCs and PCs, $\tilde{w}_{PCi}$ is the relative importances of PCs. Embedding of market-base date over TCs is performed in Phase A3. After that, the decision matrix D is constructed in Phase A4. In this phase, the evaluation value of each investment alternative is crisp, while the importances of the technical characteristics are fuzzy. In advance, weighted fuzzy decision matrix is calculated by

$$\widetilde{D} = \tilde{w}_{TCj} \otimes D. \tag{6}$$

Data-oriented shipping investment decision (DID) is performed via fuzzy axiomatic design (FAD). On the other hand, charterers' perceptions are involved by getting the fuzzy preferences in Phase C via a linguistic scale. The scale includes the following terms and related fuzzy numbers: Very Low (VL), Low (L), Moderate (M), High (H), Very High (VH) with the relevant fuzzy numbers of (0,0,3),

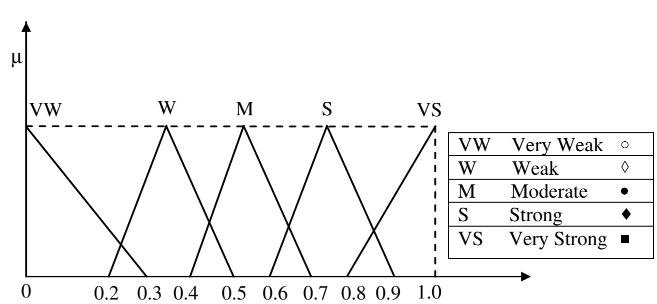

Fig. 2. Membership functions of relationships between PCs and TCs.

(1,2.5,5), (3,5,7), (5,7,9), and (7,10,10), respectively. Then, the weighted decision matrix ($\widetilde{D}_{wj}$) is calculated by using the following equation:

$$\widetilde{D}_{wj} = \tilde{w}_{PCJ} \otimes \widetilde{D}_{cj}, \tag{7}$$

where $\widetilde{D}_{cj}$ is the judgement of charterers for the jth PC. The FAD calculates the charterers' perceptions in order to identify the recent investment trends of the marine transportation markets.

The characteristics of the FAD methodology are suitable for the problem nature, hence, it supports the SoQ framework as an integrated approach especially within Phase-A4 and Phase C2. Therefore, the concept of the FAD methodology is briefly introduced as follows: the essence of the FAD methodology comes from the Axiomatic Design (AD). It is a systematic design methodology using matrix methods to analyze the transformation of customer needs into functional requirements (FRs), design parameters, and process variables (Suh, 1990). The advance characteristics of the AD principles encourage this paper to adapt FAD into the SoQ framework as an integrated unit. The main purpose of AD is to set up a scientific basis designing to improve the design activities by providing the designer with a theoretical foundation based on logical and rational thought process and tools (Suh, 2001). The AD consists of two basic axioms; (1) the independence axiom and (2) the information axiom. While first axiom maintains the independence of FRs, defined as the minimum set of independent requirements that characterizes the design goals, the second axiom minimizes the information content in a design and it generally provides a selection metric based on information content. In practice, expression of decision variables sometimes may be unclear via crisp numbers. Therefore, it is the first time that AD design approach is used under fuzzy environment by Kulak and Kahraman (2005a). Because of the deficiency of the conventional AD approach, they extend AD method to fuzzy environment to be used with incomplete information. In the literature, FAD method is used for both multi-attribute transportation company selection under determined criteria and the comparison of advanced manufacturing systems (Kulak & Kahraman, 2005b). Then, Kulak, Durmuşoğlu, and Kahraman (2005) developed weighted multi-attribute AD approaches including both crisp and fuzzy criteria. Furthermore, FAD method is used by Kulak (2005) to develop a decision support system which is a fuzzy multi-attribute material handling equipment selection system that considers the effective use of labor, system flexibility, productivity, lead time, and cost criteria. Recently, Celik, Kahraman, Cebi, and Er (2009) have proposed a FAD based technical performance evaluation model on shipyards. The formulation of the information content is given

$$I = \log_2 \frac{\text{TFN of System Range}}{\text{Common Area}}, \tag{8}$$

where I is the information content, *system range* is the properties of the system, and *common area* is the intersection between system range and design range (FRs) as in Fig. 3. The main difference of FAD methodology from the other multi-criteria methods is that it does not allow an alternative to be selected when design range = system range = common range or design range ∩ system range = ∅. To cope with this deficiency of the method, the limits of FRs can be chosen for benefit attributes for $\alpha = 0$, $\mu(\alpha) = 0$ and for $\beta = \theta = X_{\max}$ (maximum upper value of the alternative in the problem), $\mu(\theta) = 1$ and for cost attributes for $\alpha = \beta = 0$, $\mu(\alpha) = 1$ and for $\theta = X_{\max}$, $\mu(\theta) = 0$. This definition can be called ideal FR (IFR). FRs used in the proposed methodology are given in Fig. 4.

Finally, the SoQ gives the shipping managers two different decisions: Data-oriented shipping investment decision (DID) and charters' perception oriented investment decision (CPID). DID mainly routes the shipping investment decisions while CPID directly mea-

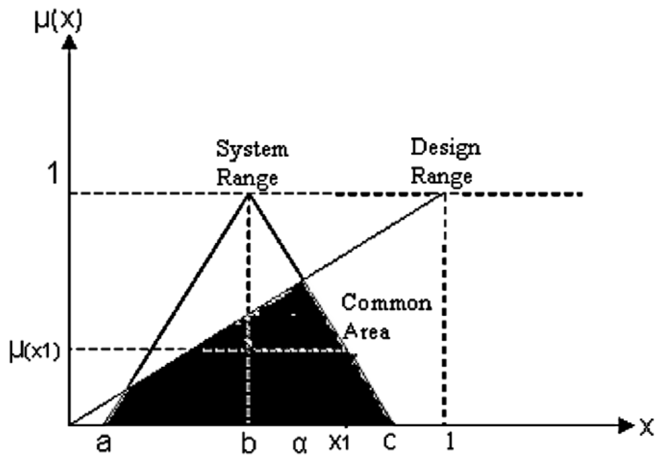

Fig. 3. System range, design range and common area.

sures the charter perceptions for different market alternatives in order to control the model consistency. If the CPID supports the DID within Phase D, the system certainly advises the ship owners to keep the investment route on the same direction. However, the system does not serve the decision aid for ship owners if there is a conflict between the two results. The relevant feedbacks between Phase E2 – Phase A3 and Phase E2 – Phase C ensure the continuity of the proposed system. The next section of this paper illustrates the SoQ on crude oil tanker markets.

3. Execution of proposed model

3.1. Motivation on global crude oil tanker market

The previous experiences about the global crude oil market have underlined the highly volatile of freight rates and unpredictable characteristics. Hence, the operation of tanker fleet has presented serious risks and incredible challenges for ship owners in practice (Kavussanos, 2003). At this point, the market analysis plays crucial roles to execute the shipping investment decisions (Lyridis, Zacharioudakis, Mitrou, & Mylonas, 2004). Typically, the tankers that have different sizes and cargo capacities transport crude oil from potential sources to pre-determined oil refineries in order to perform reproduction of products to consumers. The pricing of crude oil transportation services occurs in a highly competitive global tanker charter market under the control of critical constraints. This scope of this research covers the following crude oil tanker markets: VLCCs, Suezmaxes, and Aframaxes.

- *VLCCs*: VLCC tankers are enable to carry cargos of 200,000 dwt or greater. The *Persian Gulf–Japan, Persian Gulf–Republic of Korea, Persian Gulf–Europe, Persian Gulf–Europe, Persian Gulf–Carriben/East Coast of North America*, and*Persian Gulf–South Africa* are the well-known lines between the major oil trades of VLCCs market.
- *Suezmaxes*: Suezmax tankers can carry cargos of 120,000 to 200,000 dwt. The tanker which has the maximum size within this fleet is capable to pass through the locks of the Suez Canal in Egypt. This market has an active role on the different shipping lines between *West Africa*, *Northwest Europe*, *Mediterranean*, *and Caribbean* as medium haul oil trades.
- *Aframaxes*: Aframax tankers are operated in medium to short haul oil trades such as *Northwest Europe*,*Caribbean*,*East Cost of North America*, *Mediterranean*,*Indonesia*,*and Far East*. The tankers within Aframax markets can carry cargos at the range of 80,000–120,000 dwt.

This study aims at measuring charterers' perceptions in different crude oil tanker shipping markets. Actually, many of the professional shipping companies have requested for advisory support from maritime consultants. But, the main responsibility is carried out by the key managers (*i.e. commercial managers, technical managers, operational managers*) on behalf of the ship owners within shipping organizations. Hence, the proposed model is expected to contribute to shipping firms to establish an effective investment tool for routing the prior decisions towards selection of suitable tanker markets.

3.2. Embedding of industrial-data and feedbacks in SoQ

The availability and continuity of the data source are so critical issues to fulfil the expectations of shipping executives and relevant

Table 2
Periodical data over VLCC market

VLCC	Average spot earnings	Total number of sales	New building prices	Available number of tankers	Tonnage of shipping fleet
	$/day	Ship	Million $	Ship	Million dwt
June	44,076	3	137.5	498	146
July	32,023	7	138	501	147
August	27,855	3	138	503	147.6
September	30,538	6	142	505	148.2
October	30,142	1	143.5	508	149.1
November	22,647	3	145	503	147.7
December	219,359	1	146	506	148.7

Table 3
Periodical data over Suezmax market

Suezmax	Average spot earnings	Total number of sales	New building prices	Available number of tankers	Tonnage of shipping fleet
	$/day	Ship	Million $	Ship	Million dwt
June	45,084	9	85	353	53.2
July	24,535	7	86.5	358	54.1
August	21,272	4	86.5	355	53.6
September	22,952	0	89	358	54.2
October	43,880	6	89	361	54.6
November	27,754	4	89	361	54.6
December	109,476	2	90	361	54.7

Table 4
Periodical data over Aframax market

Aframax	Average spot earnings	Total number of sales	New building prices	Available number of tankers	Tonnage of shipping fleet
	$/day	Ship	Million $	Ship	Million dwt
June	29,225	5	67	719	73.4
July	26,165	8	68	726	74.2
August	19,719	3	68	730	74.7
September	25,598	1	70	736	75.4
October	32,900	6	70.5	738	75.6
November	27,029	11	71.5	737	75.5
December	78,234	3	72.5	741	76.1

Table 5
Pairwise comparisons of performance characteristics

FAHP	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}
y_1	1	(5,7,9)	(1,1,3)	(1,3,5)	(5,7,9)	(1,3,5)	(1,3,5)	(3,5,7)	(3,5,7)	(1,1,3)
y_2	1/(5,7,9)	1	1/(3,5,7)	(1,3,5)	(1,3,5)	1/(5,7,9)	(1,3,5)	(5,7,9)	(5,7,9)	(3,5,7)
y_3	1/(1,1,3)	(3,5,7)	1	(5,7,9)	(3,5,7)	(1,1,3)	(5,7,9)	(5,7,9)	(3,5,7)	(1,3,5)
y_4	1/(1,3,5)	1/(1,3,5)	1/(5,7,9)	1	(1,1,3)	1/(3,5,7)	(1,1,3)	(1,3,5)	(3,5,7)	(1,1,3)
y_5	1/(5,7,9)	1/(1,3,5)	1/(3,5,7)	1/(1,1,3)	1	1/(5,7,9)	1/(1,3,5)	1/(1,3,5)	(1,3,5)	1/(3,5,7)
y_6	1/(1,3,5)	1/(1,3,5)	1/(1,1,3)	(3,5,7)	(5,7,9)	1	(3,5,7)	(5,7,9)	(5,7,9)	(1,3,5)
y_7	1/(1,3,5)	(5,7,9)	1/(5,7,9)	1/(1,1,3)	(1,3,5)	1/(3,5,7)	1	1/(1,3,5)	(1,1,3)	1/(1,3,5)
y_8	1/(3,5,7)	1/(1,3,5)	1/(5,7,9)	1/(1,3,5)	(1,3,5)	1/(5,7,9)	(1,3,5)	1	(1,1,3)	1/(1,3,5)
y_9	1/(3,5,7)	1/(5,7,9)	1/(3,5,7)	1/(3,5,7)	1/(1,3,5)	1/(5,7,9)	1/(1,1,3)	1/(1,1,3)	1	1/(3,5,7)
y_{10}	1/(1,1,3)	1/(3,5,7)	1/(1,1,3)	1/(1,1,3)	(3,5,7)	1/(1,3,5)	(1,3,5)	(1,3,5)	(3,5,7)	1

Table 6
Relative importance of PCs

Weights	Fuzzy numbers
w_{pc1}	(0.08, 0.21, 0.55)
w_{pc2}	(0.04, 0.1, 0.24)
w_{pc3}	(0.1, 0.24, 0.54)
w_{pc4}	(0.03, 0.05, 0.18)
w_{pc5}	(0.01, 0.02, 0.07)
w_{pc6}	(0.09, 0.22, 0.5)
w_{pc7}	(0.01, 0.04, 0.12)
w_{pc8}	(0.01, 0.03, 0.09)
w_{pc9}	(0.01, 0.02, 0.06)
w_{pc10}	(0.02, 0.07, 0.17)

Table 7
Importance values of TCs

Weights	Fuzzy numbers
w_{TC1}	(0.23, 0.75, 2.15)
w_{TC2}	(1.64, 2.84, 3.97)
w_{TC3}	(1.64, 2.71, 3.50)
w_{TC4}	(1.92, 3.14, 3.87)
w_{TC5}	(4.04, 6.44, 7.57)

managers from the proposed mechanism. Hence, the structured framework of the SoQ is suitable and flexible to perform over the periodical statistical reports of well-known shipping consultancy firms in maritime society. For ensuring the illustrative application of the proposed model, the remaining parts of this paper will focus on the tendencies and statistical data of the crude oil tanker market in the second half of the year 2007. Mainly, the charter rates in the crude oil tanker market continued to fluctuate during the most of 2007 with parallel to the overall negative trend. Surprisingly, the sudden increases have been seemed at the last moth of the year. Tables 2–4 illustrates the statistical data over TCs of the VLCCs, Suezmax, and Aframax markets in the crude oil transportation industry, respectively (Clarkson, 2007; UNCTAD, 2007).

3.3. Performing solution algorithms over industrial feedbacks

This section enables the execution of SoQ with respect to the information flow in Fig. 1. After defining PCs and TCs, the pairwise comparison of PCs is completed in a group consensus (Table 5). The FAHP using Buckley's algorithm computes the relative importance of each PC, respectively (Table 6).

Then, the correlations between the TCs are calculated via SPSS programme by using the average value of last 6 months period of crude oil tanker markets in 2007. According to the calculated results, there are three correlations outlined: tonnage of shipping fleet – new building prices, tonnage of shipping fleet – available

Table 9
Information content value obtained from Phase A5

Market	Information contents				
	I_1	I_2	I_3	I_4	ΣI
VLCC	0.5935	1.2832	0.3677	0.0417	2.2861
Suezmax	1.2673	0.4905	0.7273	1.0192	3.5043
Aframax	1.6448	0.1371	0.0652	0.6296	2.4767

Table 8
Decision matrix

Alternatives	Technical characteristics														
	x_1			x_2			x_3			x_4			x_5		
VLCC	0.11	0.35	1.00	0.14	0.24	0.33	0.47	0.77	1.00	0.34	0.55	0.68	0.53	0.85	1.00
Suezmax	0.05	0.17	0.50	0.28	0.48	0.67	0.29	0.48	0.62	0.24	0.40	0.49	0.20	0.31	0.37
Aframax	0.04	0.12	0.36	0.41	0.72	1.00	0.23	0.38	0.50	0.50	0.81	1.00	0.27	0.44	0.51

Table 10
Weighted decision matrix

Alternatives	y_1	y_2	y_3	y_4	y_5
VLCC	(0.4, 1.47, 5.5)	(0.28, 1, 2.4)	(0, 0, 1.62)	(0.15, 0.35, 1.8)	(0.07, 0.2, 0.7)
Suezmaxess	(0.24, 1.05, 3.85)	(0.12, 0.5, 1.68)	(0.5, 1.68, 0.54)	(0.15, 0.35, 1.8)	(0.03, 0.1, 0.49)
Aframexess	(0.56, 2.1, 5.5)	(0.04, 0.25, 1.2)	(0.7, 0.24, 0.54)	(0.03, 0.125, 0.9)	(0.03, 0.1, 0.49)
Alternatives	y_6	y_7	y_8	y_9	y_{10}
VLCC	(0.45, 1.54, 5)	(0, 0.12, 0.36)	(0.03, 0.15, 0.63)	(0.03, 0.1, 0.42)	(0.14, 0.7, 1.7)
Suezmaxess	(0.27, 1.1, 3.5)	(0.05, 0.28, 0.12)	(0.01, 0.075, 0.45)	(0.03, 0.1, 0.42)	(0.06, 0.35, 1.19)
Aframexess	(0.27, 1.1, 3.5)	(0.03, 0.2, 0.84)	(0.05, 0.21, 0.9)	(0.03, 0.1, 0.42)	(0.06, 0.35, 1.19)

Table 11
Information content value obtained from Phase C1

Alternatives	Information contents (*I*)										
	y_1	y_2	y_3	y_4	y_5	y_6	y_7	y_8	y_9	y_{10}	ΣI
VLCC	0.7006	3.1108	0.5095	1.8367	2.9637	1.5252	2.3116	3.1800	3.6936	1.8238	21.66
Suezmaxess	1.0253	1.8941	1.4416	1.8367	3.5021	1.0733	3.2981	3.6749	3.6936	2.3434	23.78
Aframaxes	0.5735	1.4739	1.4416	2.7546	3.5021	1.0733	2.8194	2.7047	3.6936	2.3434	22.38

number of tankers, and available number of tankers – new building prices. Next phase, the relation between PCs and TCs are determined by using the scale given in Fig. 2. The relevant relations are indicated in Fig. 4. After that, the importance value of each TC is calculated by using the relative importance of PC and the relationship between PC and TC via Eq. (5) (Table 7).

Among the set of periodical data which are given in Tables 2–4, the data of December 2007 are inserted into the SoQ in Phase A3. Then, the decision matrix which is planned to be utilized in FAD is constructed in Table 8. Phase A5 of the SoQ is performed over the structured decision matrix. The computed information contents which are obtained from A5 for different market alternatives are presented in Table 9. According to the results of Phase A, the VLCCs market is determined as the best suitable alternative.

In parallel, Phase C of the SoQ is performed to obtain the results from the viewpoint of charterers in linguistic form in order to support the outcomes of Phase A. Then, the weighted decision matrix is calculated in Table 10. Table 11 gives the results of FAD method

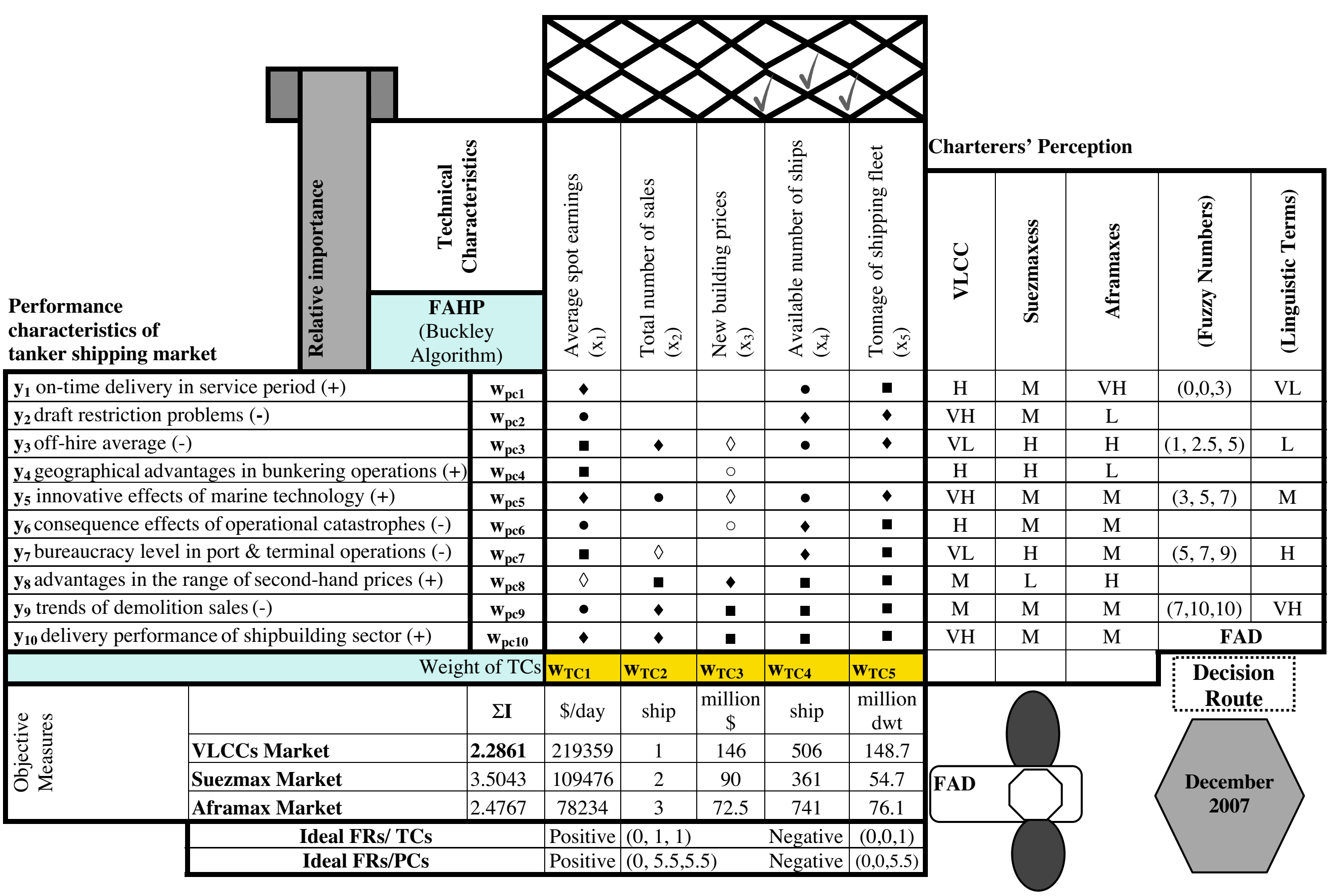

Fig. 4. Ship of Quality (SoQ) for routing investments in crude oil tanker markets.

forwarded to the charterers's perceptions. As a result, Phase C also gives the VLCCs market as the best suitable investment alternative for ship owners.

Finally, the SoQ suggests ship owners to make investments on VLCC market due to the parallel results of DID and CPID units, respectively.

4. Conclusions

The high level of managerial efforts has required for executing the shipping investment decisions in global crude oil tanker market due to the dynamic structure of maritime transportation industry. Therefore, the proposed SoQ framework overcomes the various difficulties during the initial decision process. As an effective investment decision tool, the SoQ provides the findings towards four significant points: (1) priorities of PCs of market, (2) charterers' perceptions oriented investment decision (CPID), (3) industrial-data-oriented investment decision (DID), and (4) final investment decision. The system has a self-control option for the initial results based on periodical statistics of market dynamics for coupling with the direct measurement results over customer satisfaction levels in the different market alternatives. Therefore, the SoQ ensures the reliable and satisfactory results for the relevant shipping executives. As one of the further aspects, the SoQ can be modified in order to integrate into the existing sale and purchase procedures of shipping firms. In this study, the illustrative application of the proposed model was performed on crude oil tanker shipping markets. However, the scope of the model can be extended to the container, bulk carrier, gas, and chemical markets to redesign the SoQ framework in a wide perspective.

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