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Selection of new design gas carriers by using fuzzy EVAMIX method

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ABSTRACT

This paper extends the EVAMIX (EVAluation of MIXed Data) as an exemplary multi-criteria decision-making method in three perspectives. First, the problem is investigated in a fuzzy environment. Secondly, multiple decision-makers involve in decision-making process. It allows the moderator to benefit the opinions of multiple experts. Third, experts are assigned a coefficient considering their professional career represented in years. In the conventional approach, the experts have assumed identical, but expert prioritization deals with the instability. The extensions applied in this study are currently available in the literature, and it is used for the first time in the EVAMIX method. This method can be applied to decision-making problems in any research field. A study is carried out to combine the pre-determined types of ships with reliable quantitative and qualitative criteria and create data for new investors and shipowners in the selection of ships using a novel mathematical approach. As a result of the study, preferences are modelled for candidate ships, and database and value options are presented to decision-makers, ship owners, and investors. The qualitative and quantitative data discussed in this selection process to support the decision-making process and can be designed appropriately to be used in similar selection problems. The most suitable vessel to be selected from the candidate's vessels is carried out based on the existing criteria being evaluated; therefore, it is a reference for similar methodologies.

1. Introduction

The movement of gas is a major trade within the shipping industry. As the name implies, natural gas comes out of the ground in a form that allows it to be used with little or no treatment. Petroleum gas is a byproduct of the refining process of crude oil. Ethylene is also one of the petroleum byproducts. All these 3 types of gas are carried in liquefied form and all need purpose-built ships gas carriers. Gas carriers are the most dynamic segment of the world fleet, experiencing the highest growth rate in the 12 months to 1 January 2019 (7.25 per cent) (Secretariat UNCTAD (2019), Table 2.1). There is a steady trend towards an increased number of gas-carriers (Secretariat UNCTAD (2019), Figure 2.2). It is expected that this trend will continue in view of climate concerns and environmental-protection pressure on the maritime sector to switch to cleaner fuels (i.e. gas fuels).

Recently, one of the primary instability problems for shipowners in maritime transport is the ship selection (Lai, Tao, Wang, & Zou, 2019; Sahin & Yip, 2017). The construction and commissioning of new and large vessels for use in maritime trade is a continual occurrence in the maritime sector. The difficult part for investors is to decide because identifying the appropriate vessel for the desired maritime trade is a major problem to be solved in a competitive maritime trade. As an example, the ship building sector is building new facilities to produce new ships with the technology that are complex and modern (Sahin, Senol, Bulut, & Duru, 2015). The investment of a newbuilding ship is a major capital transaction. Investment funds on a new merchant ship will always be enormous, but unfortunately the maritime market changes and effects by technology that continue developing day by day, thus there are always many uncertain and probable factors. Especially in the gas energy sector, while the current situation is volumetric, the current supply cannot meet the demand. This situation directs the investors to make decisions in uncertain market conditions that do not meet the criteria of market demand. As a result, uncertainties cause problems in the maritime sector and the gas tanker market. Shareholders of this problem are ship investors and ship owners. For investors and/or owners, the rapid, simple, and an effective way

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to solve this problem is to compare the ship under concern with an existing ship or a reference ship (Duru, Bulut, & Yoshida, 2010).

The EVAMIX method we use is based on an advanced multi-criteria decision-making analysis approach (Alinezhad & Khalili, 2019). This decision-making analysis approach system is realized by using complex and independent quantitative and qualitative qualities, as a result of which the selection period is to be shortened and the results that satisfy the investors or shipowners are to be obtained (Chojnacka & Górecka, 2016). EVAMIX method is utilized for the reference ship group preferred by the investor or ship owner and implemented for new designs. There should be more than one similar type of ship available as a reference for the decision-making system to lead the way for new designs, to provide guidance and leadership, and most importantly to make the right decision. Designers may use the multi-criteria decision-making analysis method as means of transferring it to the investor by using the existing ship as a reference in more precise ways to explain the technical, operational and reliability of the new design, so that the designer should have extra and different features at hand. This will make it a reference for new investment in the maritime sector, which is a major market, taking into account all the impacts of the ship and its related elements such as ship capacity or unrelated elements such as fire protection. The designer has to have a limited number of qualitative and quantitative options to guide the shipowner or investor correctly and make the right choice, so the options should be confined. However, the inability of the gas sector, which was affected by developments such as the shipbuilding sector, to meet the demand brought the decision problem to the investors in the market due to the increasing complexity and alternative options.

Recently, natural gas trade has gained tremendous importance and attracted attention (Devine & Russo, 2019). Given this, the importance of natural gas in the energy sector is increasing with each passing day. Natural gas sector and suppliers have become critical due to export, import, and increasing gas demand. The liquefied natural gas sector is the fastest-growing energy sectors in years. In this way, new terminals began to be built in accordance with large tonnage ships and technological design forms. As a result, the number of natural gas carriers has increased dramatically, and investors wanted to build new ships to ensure energy efficiency in the long term with high maneuverability and carrying capacity, but this has caused new decision-making problems. One of the most important new ideas is to improve fleet efficiency. The proposed multi-criteria decision-making analysis approach helps investors with qualitative and quantitative effects, such as size, technology, age, operational equipment, CO_2 or emission rate by providing similar alternatives and criteria to the decision problem, and provides appropriate and satisfactory results.

Gas carriers are a highly specialized form of ships. As Yu, Yip, and Choy (2019) showed that gas shipping is more or less independent of other shipping, this study focuses on the gas tankers in marine transport. Representative gas carriers will be selected to represent the tankers in the gas shipping sector. The results are understandable and demonstrate the applicability of the method to be developed in Section 3, 4, and 5. Marine transport is of great importance in the natural gas sector because it is the way in which large volumes are most reliably transported, supplied and delivered to the customer and operator. Liquefied natural gas is transported with special designed large ships to any industry connected to the gas sector or directly affecting the market to a large extent. In literature, few previous studies discussed the selection factors of a shipowner or ship investor in the gas tanker market. Some multi-criteria decision-making analysis has been conducted with evidential reasoning (Xie et al., 2008), AHP (Sahin & Soylu, 2020a; Wibowo & Deng, 2012), TOPSIS (Sahin, Yip, Tseng, Kabak, & Soylu, 2020; Yang, Bonsall, & Wang, 2011).

The growth in the natural gas sector and the industry connected to it depend on gas demand. Today, this increase in the natural gas sector attracts new investors. However, this energy sector, which consists of exploration, extraction, storage, liquefaction and transportation steps, creates new alternatives and criteria that have advantages and disadvantages for investors. Advantages and disadvantages that each complicated existing option affected directly or indirectly have brought the decision-making problem in the gas sector. When the mathematical analysis approach we created to solve the multi-criteria decision making problem is used effectively, reliable, appropriate and precise results can be obtained for investors.

Many methods and techniques developed in multi-criteria decision-making analysis to solve these decision-making problems can be applied by dividing the general and abstract selection criteria as quantitatively and qualitatively (Uğurlu, 2015). This research aims to evaluate objective, unrelated, quantitative and qualitative criteria for each alternative option and to combine the results by solving them. The alternatives and criteria we will use to help investors and shipowners who will make new investments in the gas tanker sector and gas transportation market.

The paper continues as follows. The literature review is in Section 2. Section 3 and Section 3.1 give the EVAMIX methodology and proposed model respectively. A detailed description of the criteria and alternatives is given in Section 4. Application and data and analysis are completed in Sections 5 and 6, respectively. Section 7 concludes the paper.

2. Literature review

This study is related to the literature on ship selection and multicriteria decision methods. Most of the relevant studies on ship selection are based on multicriteria decision methods. Popular approaches of multicriteria decision methods to ship selection include evidential reasoning (Xie et al., 2008), AHP (Şahin & Yazır, 2019; Sahin & Senol, 2015), and TOPSIS (Sahin et al., 2020; Yang et al., 2011). For the ship selection decision, criteria include (1) the investment period (e.g. 10 years), (2) the ship specifications (e.g. shipping capacity), (3) the cost of shipbuilding, (4), the newbuilding period and delivery, (5) the operation cost of the ship upon the end of the investment period (e.g. maneuverability), (6) market situation of ship chartering, (7) the cost of capital, (8) flag registration. Due to the different objectives, different criteria have been adopted. For examples, Xie et al. (2008) listed five criteria: economy, performance, equipment, appearance and automation. Wibowo and Deng (2012) listed four criteria: Operating efficiency, ship capacity, risk potential and cargo characteristics. Based on the industry survey, Sahin and Yip (2017) listed five criteria for ship selection and they are “potential for high growth”, “being in line with the regulatory requirements”, “appropriateness of the required capital to scale”, “Sustainable competitive advantage”, and “Quality of the product/service”. Based on the Balanced Scorecard framework (Kaplan & Norton, 2005), this study will consider the costing of shipbuilding, shipping capacity, and in addition fuel type to address the environmental concerns of ship emissions. Unlike previous studies, only a few studies on the gas shipping and gas tankers can be found in the literature.

In response to the rising market demand for gas tankers, gas tankers are selected for this study. The following will review the gas tanker design.

Increasing the distance and volume of the freight to be delivered in natural gas transportation has expanded the market economy by enabling new investors and ship owners to enter the gas sector. For the recipients over long distances, it is more convenient to transport using liquefied natural gas technology. For natural gas, which is intended to be delivered to many demand points, technological developments and ways to serve this purpose are enhanced. Natural gas hydrate technology is called the new non-pipeline technology for small volume natural gas transport at close distances (Gudmundsson, Graff, & Kvaerner, 2003). Natural gas is considered to be an important alternative as a transport fuel since carbon dioxide emission per unit energy is very low compared to other petroleum-based fuels (Wang, Rutherford, & Desai, 2014). Due to the increasing demand for natural gas and the lack of supply against this demand, the terminals in the natural gas supply system also have increasing importance. The biggest problem that differs in each terminal and affects gas flow is the systematic design of the terminals, and applications are provided to analyze the parameters of this design (Özelkan, D'Ambrosio, & Teng, 2008).

The method of obtaining fuel through the processing of other substances is currently in great demand with the effect of technology and has led to a decrease in natural gas prices. This decline in natural gas prices has attracted the attention of investors, leading to infrastructural developments in the natural gas transportation sector, supply chain and storage industry (Chiang & Russell, 2004; Wood, 2012). Later, the demand for natural gas increased all over the world and the desire to serve the demand in the farthest points also led to the start of intercontinental trade. To reduce the cost of energy required for liquefaction processing on ships carrying natural gas and increase the efficiency of cooling exergy and gases lost during the evaporation process, the study is carried out to reprocess the boil-off gases (Li, Jin, & Zhong, 2012; Shin & Lee, 2009). At low temperatures, natural gas transported by natural gas carrier tankers is transported at close to atmospheric pressure at long distances, while evaporation occurs when the natural gas transported in cargo tanks interacts with heat.

In general, in line with today's technology, natural gas carriers are equipped with propulsion steam turbines operating on the principle of gas compression, but with new technological advances, systems can be re-liquefied by evaporation loss resulting in more significant energy savings searched for economic solutions (Economides, 2005; Gerdsmeyer & Isalski, 2005). For small capacity, natural gas carriers, the boil-off of gas tankers caused by evaporation losses were tested, analyzed in the laboratory and comprehensive test results were evaluated (Nekså, Brendeng, Drescher, & Norberg, 2010). The effects of obtained results in the plants where the evaporation gases in small scale gas carriers liquefied are evaluated. Positive developments in natural gas transportation, procurement and related industry have forced production to increase and consequently increased the capacity and number of natural gas carriers. Ethylene obtained by the decomposition of hydrocarbons with steam is used as a chemical in many industries. Liquefaction plants in the ethylene producing countries are maintained in the liquid state, and are reduced in volume and made portable with natural gas carriers. Thermodynamic analysis of the liquefaction plants on ethylene carrier vessels increases the system performance (Ouadha & Beladjine, 2015). The gas sector, which has started to become the fastest growing sector in the world market, is faced with the problem of strategic and geographic location of the terminals planned to be built in the future (Bagočius, Kazimieras Zavadskas, & Turskis, 2014). In particular, the location of loading facilities, their connection with countries importing natural gas more than the other countries, the advantages and disadvantages that they will provide for transportation are important criteria.

Fuel consumption is the most important expenditure share of the maritime sector. To prevent the cost of fuel, many industries have been working on this subject, machine exhausts have been done, emission control has been tried and still work (El Gohary & Seddiek, 2013). International conventions also try to keep the pollution caused by the machinery on the ship at a certain level. A study on this subject aims to reduce fuel costs by using alternative fuels, to increase the efficiency of the machines used onboard, and control carbon dioxide emissions while doing so. Machine exhaust gases are thought to be an important factor in increasing energy efficiency due to the large occurrence of the ship and its high temperature. To serve this purpose, many ships are equipped with economizers called hot exhaust gas, which produces steam (Kim, Yang, Jeong, Nam, & Chang, 2014).

In gas transportation, robust technology is being developed for the delivery of the liquefied natural gas to the point where it is intended to go safely and without loss, and development is provided, and the systems required for maintaining and transporting the liquefied natural gas. In addition, the safety properties of liquefied natural gas carriers were examined and exemplified from accidents in some gas carriers (Harris, 1993; Mazloomi & Gomes, 2012).

Hydrogen is a clean gas fuel type which can be stored as compressed gas or liquid and used in some machines. If compressed hydrogen which is cleaner than natural gases, CO_2 emission is low, energy to be stored per unit volume is low is used for the machines, it is easy to supply when necessary, and it will not be difficult. Because it has little impact on environmental pollution potential, it can be used for use as fuel on ships. Hydrogen is not a primary fuel and should be produced from the combination of fossil or non-fossil energy sources with water. Hydrogen, which has a say in the energy sector, is a renewable resource, and used as an important source in sectors such as a storage and transportation (Bengtsson, 2011; Demirbas, 2000a, 2000b, 2002).

The increase in the number of gas carriers has led to the start of new facilities and the development or expansion of existing terminals. As a result of this, the number of operations of gas carriers increased and consequently, the possibility of accidents and injuries occurring during the operation increased. To this end, the problem of how to perform a risk analysis of potential accidents and injuries during the operation emerged (Elsayed, Marghany, & Abdulkader, 2014; Ferrero, Gamba, Lanzini, & Santarelli, 2016). A risk matrix system was established to estimate the failure rates of high-risk operations, enabling analysis of risks to prevent environmental pollution. The natural gas supply chain consists of gas detection, extraction, production, processing, liquefaction and transport, and they are interrelated. Any adverse situation in the manufacturing industry will cause upturns in the market and postpone the cargo to reach the buyers. As the natural gas sector is connected to the maritime and related industries, knowing the natural gas sector, advancing in line with demand and following the technology closely will be a good pioneer for future trends, alternatives and problem solutions (Lee, Cho, Lee, & Kwon, 2008; Nwaoha, Agbakwuru, & Okwu, 2016; Salgi, Donslund, & Østergaard, 2008). As a result of the increasing demand in the liquefied gas market in the world and the directing investors to this market, the gas sector has made rapid progress and achieved a great innovation in the gas market. To understand the direction of greatness with this development, analysis and statistics were generated and investigated to find out how the structure of maritime market is seen from shipowners' eyes, how the investors and experts expect the size and number of ships in the gas market (Koza, Ropke, & Molas, 2017; Specht, Staiss, Bandi, & Weimer, 1998; Wang & Notteboom, 2014).

In previous approaches, experts are assumed to be identical and the prioritization of expert's views are sensitive. The experts' evaluations are ranked by EVAMIX (Evaluation of Mixed Data) method, which is one of the multi-criteria decision-making (MCDM) methods and leads to a more stable ranking of experts' evaluations in comparison with other MCDM methods (Nijkamp, Rietveld, & Voogd, 2013; Voogd, 1982, 1983). This study further extends the concept of ship selection in a fuzzy environment, as uncertainty or

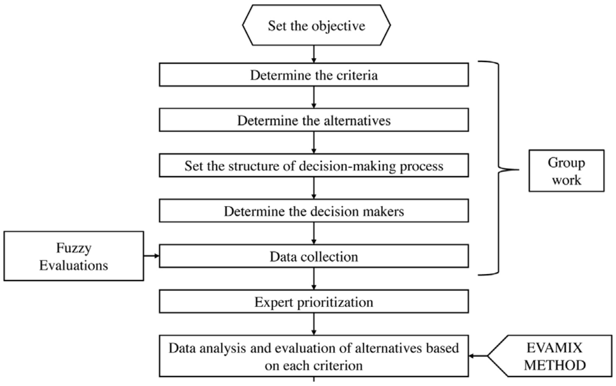

Fig. 1. Proposed EVAMIX model.

fuzziness of human evaluation should be taken into account. One of the main goals of this research is to investigate whether EVAMIX and fuzzy approach are reliable methods for ship selection. Different multi-criteria decision analysis (MCDA) methods (e.g. weighted sum model, PROMETHEE, AHP (Şahin, 2019; Sahin & Soylu, 2020b)) have features. A unique feature of EVAMIX is to take into account both quantitative (cardinal) and qualitative (ordinal) criteria within one single model. This feature gives EVAMIX, flexibility, and differentiates it from other MCDA methods. The proposed model is to combine (1) the flexibility of fuzzy approach in handling uncertainty with the ship particulars and (2) the flexibility of EVAMIX approach in handling both quantitative and qualitative criteria, and thus to provide good ship selection without comprising the consistency. For instance, PROMETHEE simply treats qualitative (ordinal) data in a quantitative (cardinal) measurement scale and the evaluation is regarded inconsistently. It is clear from the above literature review that few applications of EVAMIX exist in the fields of ship selection.

3. Methodology

3.1. Proposed model

The proposed model is presented in Fig. 1. In this model, after the objective is set, criteria and alternatives are determined by group work. The structure of the decision-making model is designed. Decision-makers are contacted and communicated via face to face or online meetings. A questionnaire is prepared for expert consultations. Data collection is conducted after several discussions and brainstorming. Relevant data might be based on crisp values or fuzzy expressions. Experts express their opinions by using linguistic terms. Data analysis and evaluations of alternatives are completed by using EVAMIX method. Finally, alternatives are ranked.

3.2. Fuzzy sets and triangular fuzzy numbers (TFNs)

In the real life, we mostly prefer expressing our thoughts and feelings in a fuzzy manner rather using numbers or crisp expressions. For example, the answer of the question "How are you?" might be "Very good!" in any artificial language, is a fuzzy linguistic variable (Bellman & Zadeh, 1977). It is an approximate expression, and hard to describe in quantitative terms. Decision support systems in all fields and levels commonly utilize linguistic variables because of its closeness to human thinking style that overcomes complex and vague situations (Zadeh, 1975).

The academic literature gets to know fuzzy sets in 1965, which is developed by Zadeh (1965). In their studies of Buckley (1985), Gupta and Kaufmann (1985), Sahin (2017), Van Laarhoven and Pedrycz (1983), Zimmermann (1991), fuzzy sets and arithmetic operations are defined as follows.

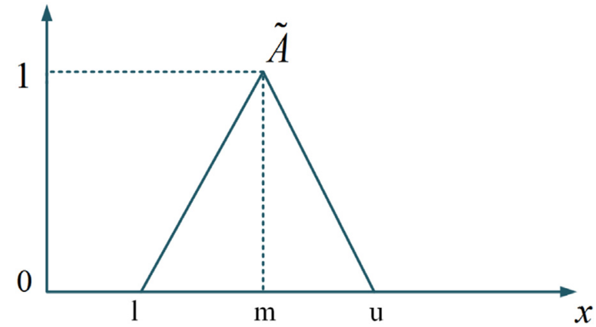

Fig. 2. Triangular fuzzy number (Zadeh, 1965).

Table 1
Membership function of linguistic scale.

Fuzzy number	Linguistic expressions	Membership function
$\tilde{A}_1$	Equally important	(1,1,1)
$\tilde{A}_2$	Moderately important	(1,1,3)
$\tilde{A}_3$	More important	(1,3,5)
$\tilde{A}_4$	Strongly important	(3,5,7)
$\tilde{A}_5$	Very strongly important	(5,7,9)
$\tilde{A}_6$	Extremely important	(7,9,9)

Let $\tilde{A}$ be a convex and normalized fuzzy subset of $X \subseteq \mathbb{R}$ of which its membership function is represented by $\mu_{\tilde{A}}(x) \in [0, 1]$, for all $x \in X$ where X is the universe of discourse.

Particulars of a triangular fuzzy number $A(l, m, u)$ is briefly

$$\mu_{\tilde{A}}(x) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le x < m \\ 1 & x = m \\ (u-x)/(u-m) & m < x \le u \\ 0 & u < x \end{cases} \quad (1)$$

where l, m and u are the lower bound, midpoint and upper bounds of fuzzy number $\tilde{A}$ as given in Fig. 2.

The operational rules between two positive triangular fuzzy numbers $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$ are given as (Gupta & Kaufmann, 1985):

Addition of two fuzzy numbers $\oplus$:

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1, m_1, u_1) \oplus (l_2, m_2, u_2) = (l_1 + l_2, m_1 + m_2, u_1 + u_2) \quad (2)$$

Subtraction of two fuzzy numbers $\ominus$:

$$\tilde{A}_1 \ominus \tilde{A}_2 = (l_1, m_1, u_1) \ominus (l_2, m_2, u_2) = (l_1 - u_2, m_1 - m_2, u_1 - l_2) \quad (3)$$

Multiplication of two fuzzy numbers $\otimes$:

$$\begin{aligned} \tilde{A}_1 \otimes \tilde{A}_2 &= (l_1, m_1, u_1) \otimes (l_2, m_2, u_2) \\ &= (l_1 \times l_2, m_1 \times m_2, u_1 \times u_2) \text{for the } \; a_i, b_i, c_i > 0 \end{aligned} \quad (4)$$

Division of two fuzzy numbers ø:

$$\begin{aligned} \tilde{A}_1 ø \tilde{A}_2 &= (l_1, m_1, u_1) ø (l_2, m_2, u_2) \\ &= (l_1/u_2, m_1/m_2, u_1/l_2) \text{for the } \; a_i, b_i, c_i > 0 \end{aligned} \quad (5)$$

The fuzzy numbers for qualitative values $e_{ij} (j \in O)$ are represented as the linguistic scale given in Table 1.

3.3. Expert prioritization

Expert prioritization concept is firstly defined by Bulut, Duru, Keçeci, and Yoshida (2012). The process of expert prioritization is formulated as follows:

Let $A=(a_{ij})_{n\times n}$, where $a_{ij}>0$ and $a_{ij}\times a_{ji}=1$ be a judgment matrix. The prioritization method refers to the process of deriving a coefficient vector of criteria $w=(w_1,w_2,\ldots,w_n)^T$, where $w_i\geq 0$ and $\sum_{i=1}^{n}w_i=1$ from the judgment matrix A. Let $M=m_1,m_2,\ldots,m_d$ be the set of decision-makers, and $\lambda=\{\lambda_1,\lambda_2,\ldots,\lambda_d\}$ be weight vector of decision makers, where $\lambda_t>0$; $t=1,2,\ldots,d$ and $\sum_{t=1}^{d}\lambda_t=1$.

Let $E=\{e_1,e_2,\ldots,e_d\}$ be the experience of each decision-makers in terms of years. λ is defined as a mean and normalization of the experiences of the decision makers:

$$\lambda_t=\frac{e_t}{\sum_{t=1}^{d}e_t} \tag{6}$$

$A^{(t)}=(a_{ij}^{(t)})_{n\times n}$ be the judgment matrix provided by the decision maker d_t. $w_i^{(t)}$ is the coefficient vector of criteria for each decision-maker calculated by

$$w_i^{(t)}=\frac{\left(\prod_{j=1}^{n}a_{ij}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{j=1}^{n}a_{ij}\right)^{1/n}} \tag{7}$$

The weighted geometric mean is conducted to obtain aggregated of the individual judgement matrix (Forman & Peniwati, 1998). Its mathematical algorithm is as follows;

$$w_i^{(w)}=\frac{\left(\prod_{t=1}^{m}w_i^{(t)}\right)^{\lambda_t}}{\sum_{i=1}^{n}\left(\prod_{t=1}^{m}w_i^{(t)}\right)^{\lambda_t}} \tag{8}$$

where w_i^{w} is the aggregated weight vector (Bulut et al., 2012).

3.4. EVAMIX method

EVAMIX method is the acronym of EVAluation of MIXed Data that is a general version of concordance analysis (Nijkamp et al., 2013; Voogd, 1982, 1983). Concordance and discordance indices are generated by conducting pairwise comparisons for pairs of alternatives in terms of the separate sets of qualitative (ordinal-O) and quantitative(cardinal-C) criteria. Dominance scores of $\alpha_{ii'}$ and $a_{ii'}$ for ordinal and cardinal criteria are computed respectively as given below.

$$\alpha_{ii'}=f(e_{ij},e_{i'j},\pi_j),\quad \forall j\in O \tag{9}$$

$$a_{ii'}=g(e_{ij},e_{i'j},\pi_j),\quad \forall j\in C \tag{10}$$

where $a_{ii'}$ means that alternative a_i dominates $a_{i'}$.

$$\alpha_{ii'}=\left[\sum_{j\in O}\{\pi_j sgn(e_{ij}-e_{i'j})\}^c\right]^{1/c} \tag{11}$$

$$a_{ii'}=\left[\sum_{j\in C}\{\pi_j sgn(e_{ij}-e_{i'j})\}^c\right]^{1/c} \tag{12}$$

where

$$sgn(e_{ij}-e_{i'j})=\begin{cases}+1 & \text{if } e_{ij}>e_{i'j}\\ 0 & \text{if } e_{ij}=e_{i'j}\\ -1 & \text{if } e_{ij}<e_{i'j}\end{cases} \tag{13}$$

where π_j is the weight of the corresponding criterion, e_{hj} is the evaluated value of alternative a_h in terms of criterion g_j, c is an odd number as 1,3,5, ...

Then, standardization is required to unify $a_{ii'}$ and $\alpha_{ii'}$, since quantitative values are assigned considering $0\leq e_{ij}\leq 1$ scale, and qualitative values $e_{ij}(j\in O)$ are represented as the linguistic scale as proposed in Section 3.

Standardized dominance measure is given as follows:

$$\delta_{ii'}=h(\alpha_{ii'})=\frac{(\alpha_{ii'})-\alpha^-}{\alpha^+-\alpha^-} \tag{14}$$

$$d_{ii'}=h(a_{ii'})=\frac{(a_{ii'})-a^-}{a^+-a^-} \tag{15}$$

Overall dominance measure $D_{ii'}$ for each pair of alternatives $(a_i,a_{i'})$ is computed as follows.

$$D_{ii'}=\pi_o\delta_{ii'}+\pi_c d_{ii'} \tag{16}$$

$$\pi_o=\sum_{j\in O}\pi_j \tag{17}$$

$$\pi_c=\sum_{j\in C}\pi_j \tag{18}$$

Final appraisal score (s_i)

$$s_i=\left[\sum_{i'}\frac{D_{i'i}}{D_{ii'}}\right]^{-1} \tag{19}$$

where

$$D_{ii'}=\frac{s_i}{s_i+s_{i'}}\quad D_{ii'}+D_{i'i}=1 \tag{20}$$

4. Particulars of criteria and alternatives

With reference to the well-established Balanced Scorecard (Kaplan & Norton, 2005; Sahin & Yip, 2017), we choose four criteria (financial, technical, environmental and operational) in this section. In the Balanced Scorecard framework, it includes financial, innovation & learning (or technical), customer and internal (or operational). The relevance of the Balanced Scorecard with the context of the company would create more value to its application in ship investment. In this empirical study, the four criteria are divided into two groups as quantitative and qualitative criteria. Definitions of the criteria are given as follows.

4.1. Criterion 1 – Financial attribute

During the ship selection process, three factors are considered based on the financial attribute.

4.1.1. Cost of shipbuilding

The cost of shipbuilding may vary depending on the shipyard where the ship is built, the parallelism of the ship type with the technology, the material on which the ship is built, the quality and life span of that material, the complexity of the ship type, and similar reasons. Shipbuilding facilities are also a repair center for ships. While the demands of the market shape the shipbuilding sector, it should be able to provide technical reliability and commercial benefit to the investor or ship owner in parallel with the new innovations and technological developments (Chupin & Grigor'ev, 2018). Today, bulk cargo carriers and tanker ships take the largest share in the shipbuilding sector. In the tanker shipbuilding sector, where there is a big race, cost of shipbuildings are determined by the countries that have the biggest share, some of which are China, South Korea and Japan. Considering the number and type of ships constructed by these countries at an annual rate, it is seen that the biggest shareholder of the growth in the tanker ship construction sector is the gas tanker sector. Faced with increasingly fierce competition, the strengths of this sector need to be measured, demand identified, and a pre-construction decision-making mechanism set up. The strength, stability and cost of shipbuilding can be considered as the most important points in the decision-making process for investors (Jiang, Bastiansen, & Strandenes, 2013).

4.1.2. Present value

Some reasons make the gas sector attractive to the investor. The first of these is the current freight prices and the future freight rates of the gas energy sector. The other is that there are no extraordinary events occurred that will adversely affect the investor's expectations from the sector. Lastly, it is the sector where the probability of occurrence of an accident, explosion, fire, and similar events is low. The investors use their resources depending on their trust in the sector. That is, the well-estimated freight price, in the long run, will increase the investor's success and confidence. The main goal of predicting future prices is to reduce uncertainty. Long-term maritime investments and forecasts are generally less at risk. Gas sector freight prices, which are estimated in the long term, give the investor confidence. Choosing the ship and deciding to build it is an investment problem. The most important source of this investment problem that reassures ship owners and new investors is the current freight prices of the gas industry today. The gas sector freight prices for the next five years also give confidence to investors (Goulielmos & Psifia, 2011). Between 2007 and 2013, the size of the gas sector and natural gas production increased 5% more than the estimate (Brehm, 2019). Investors or shareholders in the maritime sector make plans by taking into account the current situation of the market and the current freight price, which is the most important factor as an output of the production function in the evaluation of the investment. Therefore, the investment is reviewed by considering the existing factors as well as future factors. The total economy of the energy sector is relatively more extensive than that of the natural gas transport market, but the share of the natural gas transport market in maritime transport is greater than that of other energy sources, and the dynamics are different. Due to the effect of supply-demand, there are changes in current prices in the market, which are one of the most important features of the natural gas transportation sector. Because the different systems used in gas carriers in compliance with national and international rules create extra costs that are not available in other maritime transport sectors (Adland, Jia, & Lu, 2008; Kumar et al., 2011). It increases the volatility of the current freight price in the market with new and large scale vessels and regions where these vessels are navigating in the completely competitive gas transportation sector.

4.1.3. Average freight rate

Freight prices in the natural gas market are changing with rising commercial tendencies. These are tendencies that change with and without depending on time. The fact that the same market is high or low in other countries creates factors that affect these tendencies positively and negatively. Although freight prices depend on subunits, industries and dynamics in the other bulk cargo transport sector, they are affected in the same way with a different tendency in the gas sector (Bai & Lam, 2019). To carry the gas in liquid form at atmospheric pressure and temperatures, system and equipment on gas carriers are different than oil carriers. Due to those specific systems which machine and control mechanism used, it is influenced by the developments in different sub-units and determines the freight prices according to sources. In general, a factor that appears to have an impact on the entire maritime transport market does not have the same impact on the gas transport market. The reason for this separation is that the natural gas sector has dynamic ties with the maritime sector as well as other sectors. This is one of the important criteria of investors and shareholders. Between 2007 and 2013, the natural gas market went down considerably for some reason. During these years, investors and shipowners concentrated their preferences on gas markets, which led to a decline in other energy markets. Thus, the number and production of natural gas terminals increased. Since natural gas prices have a say in the production in the energy sector, future natural gas price analyzes are also closely followed by investors in the energy sector. When the natural gas market became attractive for ship owners and investors, extra investments were made in their gas carrying capacity. While natural gas market prices are expected to fall until 2007 and production is expected to decrease, this development has led to widespread expansion and the formation of a supply chain (Brehm, 2019).

4.2. Criterion 2 – Technical attribute

4.2.1. Shipping capacity

The vessels used for natural gas transportation purposes were first used as mini carriers, and later the capacity of liquefied natural gas vessels began to be increased with new technological developments, development of the sector and rapid transportation possibilities (Ha, Ha, & Lee, 2013). As the natural gas sector, which is still in demand today, has expanded, new trends and studies have emerged. The most striking of these is that new systems have been produced so that to decrease emissions rate, and to avoid extra and different fuel costs by natural gas carrier ships can be used as fuel to increase the amount of cargo that can be transported on the ship. As a result, the amount of cargo that is carried by a gas ship increased. Ship selection problems have also arisen due to the carrying capacity of ships (Xie et al., 2008). That is, the carrying capacity criterion of ships is noteworthy as it is vital for shipowners and new investors to meet the demand in the gas transportation sector. Liquefied natural gas is 600 times less than the same amount of gas at the same room temperature, which is the most economical way for ship owners to transport large amounts of natural gas over long distances. Natural gas production and storage are price-determining factors in the natural gas sector. Gas transported with the determined prices will not affect gas prices much in the short term when transported by carriers with high storage and transportation capacity. The higher the total amount of gas transported, the lower the revenue per unit cost will be as the investor wishes. For this reason, new investors and ship owners prefer ships with high storage and transportation capacity, especially for long-term voyages. The investor, who wants to overcome the sudden demand shocks, wants to carry the high capacity of natural gas, which has less carbon emission and high demand in the energy sector. Newly constructed gas carriers with high storage and transport capacity are more demanded for the mentioned reasons (Brehm, 2019).

4.2.2. Fuel consumption

Fuel consumption is important for all sectors in the maritime market. Future studies show that new drive systems are being developed together with the technology and that this alternative consumption is aimed to be minimized. In parallel with this goal, the new ships produced today are equipped with systems with different equipment and will provide long-term profit to the owners (Bortnowska, 2009). The developments in the ethane gas market in the United States are closely followed, as the ethane gas is very much emerging because of the developing oil natural gas facilities and market in the United States (Jadidzadeh & Serletis, 2017). This emerged as an alternative to the fall in price due to the abundance in the ethane gas market and to price-shaping the naphtha, which was shaped by the developments in the crude oil market. They are designed and modernized to use ethane as an alternative fuel in the new generation ethane carriers (Thomson, Corbett, & Winebrake, 2015). By working on new gas engines that burn ethane gas as fuel started to be produced with the help of technology. Nowadays, some companies are using ships with gas engines working by burning ethane gas in order to save energy and fuel consumption and order new ships with the same gas engine system for the future (Poulsen & Johnson, 2016). Due to the great developments in the natural gas sector, a cheaper and cleaner energy production has been achieved, and in the short term it has also reduced the carbon emissions from electricity generation and operations on gas carriers. The carbon emission estimation strategy for fuel consumption of gas carriers shows that the carbon emission rate is gradually decreasing. As a result of the analyzes, it proves that the clean energy-based investment of the gas sector reduces carbon emissions depends on fuel consumption to lower levels within a 5-year period. Since natural gas prices have a say in the production in the energy sector, future natural gas price analyzes are also closely followed by investors in the energy sector. Gas-fueled vessels are noteworthy in terms of emissions and fuel consumption. Construction of gas-fueled ships is encouraged due to low gas prices. Fuel consumption and carbon emission rates of gas-fueled vessels will affect this situation. Production of gas-fueled vessels, fuel-type change is increasing, but carbon emissions and gas-fuel consumption capacity are reduced, provided gas prices continue to remain low (Brehm, 2019).

4.2.3. Loading facilities

Since the increasing demand in the natural gas sector has led to an increase in production, more facilities have been started to be built to meet the demand. In order to more gas-carrying tankers to come to the facilities, the facilities need to be expanded and improved, free of hazards (Oka & Ota, 2008). Adequate precautions should be taken against threats by raising awareness of potential threats so that protection of natural gas vessels during operations at the facilities is ensured (Pitblado, Baik, Hughes, Ferro, & Shaw, 2005). Some threats at the facility are considered high risk for ships carrying natural gas (Pitblado, 2007). The most important of these is environmental pollution, for which facilities must be designed with safe equipment, mechanisms and subsystems and have applications or programs to predict the risks that may occur. Hazardous operations in the past have been caused by a flawed analysis of risks and incorrect operation. Due to these undesired events, the level of the necessary measures in the facilities should be higher than the gas carriers so that the natural gas carrier ships can operate smoothly in the facilities. The future situation of the natural gas market is determined by the countries with the largest export rates and by the technological, large, countries with many gas terminals. These factors generally vary depending on the rate of construction of new and technological processing plants, development of export infrastructures, new and / or alternative energy investments, and energy policies of countries with large gas export rates (Luke & Noble, 2019). Natural gas bunker vessels, which are originated from the construction of gas-fueled ships, were also produced. Falling natural gas prices and rising production terminals have had their effects in the long run. After the great development of the gas sector, the production of gas-fueled power plants increased. The production of these modern power plants has also attracted the attention of investors who have a share in the energy market. The decrease in gas prices and the fact that they do not remain high is the most desired effect for these gas-fueled power plants. The rate of construction of these power plants has been able to reduce all carbon emissions by exceeding all estimates made during the period of high gas prices. The plan and construction of gas-fueled power plants aiming to reduce carbon emissions require major investments. Investments made using large capitals increase the value of gas market and natural prices. Research shows that although large terminal building investments have negative impacts on the gas market, their positive effects will be greater as they continue to operate in the future (Brehm, 2019).

Definitions of the qualitative criteria are given as follows.

4.3. Criterion 3 – Environmental attribute

4.3.1. Fuel type

The biggest problem of our globalizing world is climate change, greenhouse gas, carbon dioxide emission, sulfur and nitrogen components emission rate Nahlik, Kaehr, Chester, Horvath, and Taptich (2016). In many industries and sectors, many new applications and studies are emerging in order to solve these problems of our world and reduce these rapidly growing harmful effects. In order to prevent this problem in future ship types and current maritime sector, the focus is on new systems and machines that cause less emissions, different fuel usage and improved filter usage in the equipment that provides the propulsion of ships (Deniz & Zincir, 2016; Yoo et al., 2013). For the use of alternative fuel, which is one of these ideas, liquefied bio gas, methanol and bio-methanol and liquefied natural gas were emphasized and studies were carried out. Using fuels of this option is to improve the performance of environmental factors, increase environmental functions, reduce environmental pollution, and provide the solution to the problems of harmful fuels in today's and future worlds (Elgohary, Seddiek, & Salem, 2015). Emission rates from carriers such as liquefied petroleum gas carriers are very high and seriously affect air quality and air pollution. Employees also have a high impact on their health. The oil and gas sector has modelled new emissions distribution and levels to control and minimize this situation. Mapping and analysis programs have been developed for gas carriers and other carriers in order to minimize the maximum ozone concentration and control their economic and ozone health effects (Brynolf, Fridell, & Andersson, 2014). Due to the high emissions in gas carriers, new conventions and new measures have resulted in extra costs for the shipowner and the investor. Different geographical areas bring about different measures and different risk assessments. Air quality decreases due to the activities carried out in gas carriers and endangered human health. Improved air quality modelling approaches should be used in order to minimize this situation and gain insight into their economic value (Fann et al., 2018).

4.3.2. CO_2 emission

Particular attention is paid to natural gas carrier ships, since carbon dioxide emissions are an important environmental and economic factor. Systems and equipment in ships aim to minimize carbon dioxide emissions and to provide transportation using different propulsion systems. There are special requirements and international criteria for ships navigating in the emission control area and sulfur emission control area. With these conditions and international criteria, emission rates have been tried to be reduced and the systems on board are improved in line with the criteria and conditions. In the newly constructed ships, special systems and mechanisms have been started to be established to keep the emissions under control by reducing the emission rate and to be able to monitor the current developments. Liquefied gas carriers are more flexible than other types of ships in the use of different types of fuel in order to save energy and provide energy efficiency because of the new propulsion systems and their parallelism with current technology (Burel, Taccani, & Zuliani, 2013). Due to current technological propulsion systems, machine gases are used in different fields in gas carriers. Natural gas-fueled vessels have 4 times larger units than other fueled vessels. Natural gas-fueled ships bring fuel consumption cleaner and still reduce the negative impacts on environmental impacts. The biggest of these impacts is the reduction of CO_2 emissions. Natural gas-fueled vessel units also minimize some other pollution from fuel consumption. For all these reasons, the efficiency of ships equipped with natural gas-fueled units will be higher than other vessels, while at the same time CO_2 emissions will be reduced significantly. Gas turbine units and different propulsion systems used in natural gas-fired ships are recognized as a clean way of generating energy. These systems and units have a positive impact on CO_2 emissions, other environmental impacts and high efficiency in energy generation (Dorsey-Palmateer, 2019). The overall emission rate decreased by 11% due to electricity and energy production. The energy sector, which affects the gas market in this process, has managed to influence all sectors along with increasing natural gas production capacity, renewable energy terminals and demand. According to the calculations, it has been announced that carbon cost has decreased by 5.1 billion dollars (Brehm, 2019). In addition, new modelling systems are used to estimate the overall fuel consumption and emissions of gas carriers.

4.3.3. Fire protection

In the gas sector, which proliferated, deaths due to big fires and explosions also increased in parallel. Fire and explosion risk assessments in gas carriers have been analyzed by several methods (Jiang et al., 2013). The results of the analysis show that in gas carriers, which are the most deadly hazardous tanker type, if safety methods are not developed and/or necessary measures are not taken, this rate will increase day by day. It is extremely important to analyze this risk in gas carriers and solve potential problems by evaluating them in terms of security. Fire and explosion, which pose a great risk to the environment and human health, is one of the most important hazards for tanker ships (Elsayed, 2009). Special systems and control mechanisms are used by ships and facilities to prevent incidents such as explosions and fires, so that ships and facilities maintain operating standards and are constantly controlled to ensure their continuity. Risk analysis systems are being developed to provide continuous and up-to-date control of these systems (Elsayed, Leheta, & Belhaj, 2011; Planas-Cuchi, Gasulla, Ventosa, & Casal, 2004). Since there is a continuous production and an operation in the natural gas sector, it is inevitable to ensure the maintenance and protection of systems that provide fire and explosion controls on ships carrying liquefied natural gas. In order to prevent and detect leaks, improved systems are used in ships carrying liquefied natural gas. The reasons for creating a fire potential or increasing the risk of explosion on ships carrying gas should be analyzed (Fay, 1973). Since the refuelling and loading systems are operated by high pressure, they are combined with specially designed equipment that reduces the risk of fire. Due to the high retention properties of natural gases, necessary systems have been designed against leakages since they can easily ignite in case of leakage. Fires and explosions that may occur can be controlled by ships and facilities in the absence of leakage, but in the event of leakage, the fire may cause a large amount of energy, causing disaster. Gases carried as liquids are in fact not flammable, but the vapors generated during the return to the gas phase may ignite when they meet a certain air content. For the prevention of leaks, detectors, reliable fire fighting technological systems, alarm systems designed with backups, emergency shutdown systems, temperature sensors, fault and error reporting systems and all similar functions are used on ships carrying natural gas (Lee, Seo, & Chang, 2015).

4.4. Criterion 4 – Operational attribute

4.4.1. Manoeuvrability

Additional some equipment can be added to the new vessels besides their requirements to increase the maneuverability of the vessel and use the vessel at maximum efficiency. While the maneuverability of the ship is enhanced with the help of some additional equipment, it allows the ship to go to different ports and at the same time provides resistance to bad weather conditions (Ventikos, Louzis, & Koimtzoglou, 2018). Ships with high maneuverability will allow for safe navigation if the conditions are also taken into consideration. This opportunity will allow the ship to reach new ports and new facilities. It is very important to deliver natural gas, which constitutes the highest demand rate of the energy sector, to the demanded places. The most important task in this regard falls on ships carrying natural gas. One of the conditions for a ship to visit many ports is that it has high maneuverability and the draft level is suitable for the port to be reached. Evaluating the ship's maneuverability is crucial when choosing a ship. The most important feature that the ship should possess for its high maneuverability is the driving force with high efficiency. The investor, who wants to serve the natural gas energy demanded by many countries, can provide this supply to more than one customer with ships which have a high maneuverability. Due to the turbine systems used in natural gas carrier ships, maximum side force and yawing moment can also be produced fast, and so precise maneuver can be provided in a limited area as well as high propulsion (Jaswar, Loh, & Prayitno, 2013).

4.4.2. Incident and accident

Liquefied natural gas plants are a potential hazard to around because of their basic properties found in natural gas itself (Starosta, 2007). There are many different applications and systems in liquefied gas carriers and associated facilities and terminals in order to prevent accidents and injuries and take care of the environment and prevent pollution (Er, 2007). The first of these measures is to construct and equip the facilities away from land, towards the open sea and with suitable, durable materials. The tanks used in liquefied natural gas carriers and all storage areas of this sector are specially designed, constructed, equipped with the necessary systems and tested and put into service. Liquid cargoes carried by sea have more severe toxic, irritant and toxic properties, but this ratio is less in ships and terminals carrying liquefied natural gas compared to other types of liquid cargo (Akyuz, 2017). According to other types of tanker, only some marine events occurred in a 45-years period in the gas sector, and none of these events had a massive loss or large gas leakage. As a result of these accidents, only minor structural damage occurred on the ships and cases such as death or explosion/fire due to large oscillations did not occur much. These results have increased shipowners' and new investors' confidence in the gas industry of energy market and encouraged investors for larger investments. New transport models developed with technology provide a protective shield for accidents and causes, making operations faster and more reliable and improving regulations. This situation gives the investor confidence for the gas sector. Research shows that the biggest risks in natural gas carriers are collision, grounding, contact, fire and explosion, respectively (Nwaoha, Yang, Wang, & Bonsall, 2011). These analyzes were also used to identify high-risk areas in gas carriers. It has been observed that most of the events listed above occur during navigation or during loading/unloading operations at the terminal. Liquefied gas, which is poured on the sea surface as a result of any accident, floats because it is lighter than water and does not create a long-lasting pollution. Cost-effective risk reduction system is required to prevent these incidents/accidents and to take feasible measures. Different risk models and costs applied to prevent each potential factor offer an important choice for investors (Vanem, Antão, Østvik, & de Comas, 2008).

4.4.3. Seaworthiness

There are many criteria and equipment for seaworthiness, especially for tanker ships, since it means that the risk of ships carrying dangerous cargoes will be greater. Tanker ships that require operational attention also are equipped with sufficient personnel to serve the purposes of this system. The existence of systems suitable for cargo to be transported and the ability to respond to changes or undesirable conditions are parts of the seaworthiness criteria. The maritime sector, which is one of the sectors that can develop faster than others in terms of technology, is being tried to be made suitable in many long-distance voyages with the automation of the ships and the increase of machines sensitive to the marine environment and ecology (El Gohary & Seddiek, 2013). With the development of the transport industry and the globalization of trade, modern ships have been developed and transport capacity increased, which has led to lower transport prices. The increase in supply and interest in transportation services increased the demand. When other types of transportation are compared with maritime transport, it will be seen that the supply chain has a large share in the gas sector. High emission pollution, high overall fuel consumption, direct interaction with marine ecology and nature are among the reasons for the high environmental impact and controls in maritime gas transport sector (Deniz & Zincir, 2016). When the fuel consumption and emission analysis values of the gas carriers are evaluated, the results are of concern, which has led the gas sector to find alternative fuels and to produce new and modern propulsion forces to reduce the emission values. In addition, new modelling systems are used to estimate the overall fuel consumption and emissions of gas carriers (Cullinane & Bergqvist, 2014).

Gas carriers are a highly specialized form of ships. The three classes of gas carried are liquefied petroleum gas (LPG), liquefied natural gas (LNG) and liquefied ethylene (LEC). Different from LPG and LNG carriers, LEC carriers are semi-refrigerated. Gas carriers are selected for this study because (Yu et al., 2019) showed that gas shipping is more or less independent of other shipping, and thus other ship types are not considered.

In this empirical study, there exist three alternatives as Liquefied Petroleum Gas Carriers (LPG), Liquefied Natural Gas Carriers (LNG) and Liquefied Ethylene Carriers (LEC).

Alternatives of the ship selection problem are described as follows:

4.5. Alternative 1 – Liquefied petroleum gas carriers (LPG)

Petroleum gas carriers which are capable of carrying petroleum gases in bulk form, which are produced for commercial purposes, and which are pressurized and liquefied, are used for transferring certain gases such as ammonia, propylene, vinyl chloride, and the like. The cargo lists on the gas carriers determine what kind of gases the gas carrier can carry. Since the boiling point of the cargo carried generally varies between 229 °K and 273 °K, these tanks should consist of specially produced heavy steels. Liquefied petroleum gases generally consist of butane and butylene, which are colorless, odorless, and heavier than air, mixtures of hydrocarbon propane or mixtures of gases which will not disperse without wind, which require high heating value. Liquefied petroleum gases are used as a dry gas, and since they have a high ignition temperature, the ignition system of the machines using liquefied petroleum gases, the fuel systems, the areas where the fuel system is connected, the storage tank and the general tank integrity require special care, handling and supervision. Special care and handling of the fuel filters must be carried out and inspected within the scheduled time and replaced at regular intervals. For this reason, the cost of this type of gas carrier is high.

4.6. Alternative 2 – Liquefied natural gas carriers (LNG)

These are special ships designed to transport cargo at −162 °C boiling point, equipped with independent cargo tanks or membrane cargo tank type. The independent cargo tank type, which is one of the cargo tank types, is designed to support itself while it does not provide support to the power in the ship and hull. The natural gas produced in the facilities is also transported by liquefied natural gas carriers using the sea route in liquefied form after some processes (Shibasaki, Usami, Furuichi, Teranishi, & Kato, 2018). Natural gas, which is the most valuable clean and non-toxic energy source in the world after coal and oil, which has a big say in the energy sector in the world, transports approximately 75 million tons by sea only every year.

Table 2
Expert profiles.

Expert number	Job position	Experience on gas carriers [years]	Education
1	Officer	3	B.Sc.
2	Chief Officer	5	B.Sc.
3	Shipmaster	7	M.Sc.
4	Shipmaster	8	M.Sc.
5	Shipmaster	9	M.Sc.
6	Chief Officer	4	B.Sc.

4.7. Alternative 3 – Liquefied ethylene carriers (LEC)

Ethylene is one of the most important building blocks of the petrochemical industry which is cooled at boiling point under atmospheric pressure conditions. It is obtained from the processing and decomposition of liquefied petroleum gases. Worldwide, 85 million tons of ethylene are produced annually and used in many industries. These 85 million tons of ethylene are generally used in other industries close to the plants where they are produced, so the amount of ethylene put on the market for transportation to the demanding regions by sea transport is only 3 million tons. Ethylene, which is intended to be transported by sea, is carried by liquefied ethylene carriers or by semi-pressured carriers. These ethylene carrier vessels are also capable of carrying a variety of chemically liquefied gases. These vessels are very well insulated and have steel cargo tanks.

5. Application

The empirical study is designed as three alternatives based on four criteria. Two of the criteria are qualitative, and the other two are quantitative ones. As shown in Table 4, alternatives are evaluated in a fuzzy manner depending on the qualitative criteria (Criterion 1 and Criterion 2). Six anonymous decision-makers are contributed to the decision making process. Decision-makers are chosen from among shipmasters in the field. The decision-makers are experienced in tanker transportation. Experience years of decision-makers ($DM_1, DM_2, \ldots, DM_6$) are 3, 5, 7, 8, 9 and 4 respectively. Profiles of the experts are given in Table 2:

Decision-makers are given the technical specifications of all ships before the expert consultations, and made sure that they have a piece of complete knowledge on the alternatives and criteria. The general framework of the empirical study is provided in Table 3. This framework is designed based on field expert consultations, current literature and updated indexes (Bunker Index, 2020; Lindstad, Asbjørnslett, & Strømman, 2012).

Table 4 shows evaluation matrices have been constructed where alternatives and evaluation criteria (qualitative). The set of evaluation criteria ($j = 1, 2, 3$) and the set of alternatives ($i = 1, 2, 3$) for each attribute. The lambda λ values show the weights of experts.

Table 5 shows weights of each criterion, crisp and aggregated fuzzy judgments for alternatives. Aggregated fuzzy judgment matrix for criteria is computed based on Eq. (8).

Qualitative and quantitative dominance scores are given in Tables 6 and 7 respectively, as defined by Equation 9 and 10.

Table 3
General empirical framework for expert evaluations.

	Financial attribute		
	Cost of shipbuilding	Present value	Average freight rate
LPG	11,300 Million USD	372 Dolars	Important
LNG	7,600 Million USD	506 Dolars	Important
LEC	15,350 Million USD	606 Dolars	Important
	Technical Attribute		
	Shipping capacity	Fuel consumption	Loading facilities
LPG	76.300 DWT	Very Important	gettable
LNG	53.300 DWT	Very Important	easy-to-get
LEC	51.600 DWT	Very Important	hard-to-get
	Environmental attribute		
	Fuel type	CO2 emission	Fire protection
LPG	Petroleum gas	85%	High risk
LNG	Natural gas	38%	High risk
LEC	Ethylene	50%	High risk
	Operational attribute		
	Maneuverability	Incident and accident	Seaworthiness
LPG	Low-wheel engine	High rate	Available
LNG	High-wheel engine	Low rate	Available
LEC	Mean-wheel engine	Mean rate	Available

Then, the standardization for both qualitative and quantitative dominance scores as given in Tables 8 and 9 . The dominance scores of Tables 6 and 7 are standardized by the linear normalization as specified in Equation 14 and 15 such that all the values of dominances scores range from zero to one and become comparable.

The values of overall dominance measure are given in Table 10. The values of measure are calculated by Equation 16, and denote the weights of importance of each criterion (ordinal or cardinal) for each pair of alternatives. The overall dominance score reflects the degree to which alternative dominates another alternative for a given set of criteria and weights.

Table 4
Fuzzy judgment matrix for alternatives.

		Criterion 1	Criterion 2
DM_1 ($\lambda = 0.08$)	Alternative 1	(1 3 5)	(7 9 9)
	Alternative 2	(1 3 5)	(1 3 5)
	Alternative 3	(5 7 9)	(1 1 1)
DM_2 ($\lambda = 0.14$)	Alternative 1	(3 5 7)	(1 3 5)
	Alternative 2	(3 5 7)	(3 5 7)
	Alternative 3	(1 3 5)	(7 9 9)
DM_3 ($\lambda = 0.19$)	Alternative 1	(1 1 1)	(1 3 5)
	Alternative 2	(1 1 1)	(7 9 9)
	Alternative 3	(1 1 1)	(5 7 9)
DM_4 ($\lambda = 0.22$)	Alternative 1	(3 5 7)	(5 7 9)
	Alternative 2	(5 7 9)	(1 3 5)
	Alternative 3	(3 5 7)	(3 5 7)
DM_5 ($\lambda = 0.25$)	Alternative 1	(1 1 1)	(1 1 1)
	Alternative 2	(1 1 1)	(1 1 1)
	Alternative 3	(1 1 1)	(1 3 5)
DM_6 ($\lambda = 0.11$)	Alternative 1	(5 7 9)	(5 7 9)
	Alternative 2	(3 5 7)	(7 9 9)
	Alternative 3	(1 3 5)	(3 5 7)

Table 5
Weights of each criterion, crisp and aggregated fuzzy judgments for alternatives.

	Qualitative O 0.60		Quantitative C 0.40	
	0.65 Criterion 1	0.35 Criterion 2	0.25 Criterion 3	0.75 Criterion 4
Alternative 1	(1.78 2.43 2.95)	(2.01 3.31 4.27)	0.55	0.35
Alternative 2	(1.88 2.53 3.03)	(2.11 3.42 4.19)	0.35	0.20
Alternative 3	(1.46 2.21 2.77)	(2.58 4.46 5.95)	0.10	0.45

After all computations, the final appraisal score is calculated as given in Table 11. The higher the appraisal score the more is the alternative preferred. This, the most preferred gas carrier is the one with the highest appraisal score.

Table 6
Qualitative dominance score.

											c=1	($\alpha_{ii'}$) Mean
Alternative 1 vs. Alternative 2 $sgn(e_{ij} - e^*_{ij})$												
Criterion 1	$e_{11} - e_{21}$	−1	−1	−1	−0.65	−0.65	−0.65		−0.65	−0.65	−0.65	
Criterion 2	$e_{12} - e_{22}$	−1	−1	1	−0.35	−0.35	0.35		−0.35	−0.35	0.35	
								α_{12}	−1	−1	−0.3	−0.7667
Alternative 1 vs. Alternative 3 $sgn(e_{ij} - e^*_{ij})$												
Criterion 1	$e_{11} - e_{31}$	1	1	1	0.65	0.65	0.65		0.65	0.65	0.65	
Criterion 2	$e_{12} - e_{32}$	−1	−1	−1	−0.35	−0.35	−0.35		−0.35	−0.35	−0.35	
								α_{13}	0.3	0.3	0.3	0.3
Alternative 2 vs. Alternative 1 $e_{ij} - e^*_{ij})$												
Criterion 1	$e_{21} - e_{11}$	1	1	1	0.65	0.65	0.65		0.65	0.65	0.65	
Criterion 2	$e_{22} - e_{12}$	1	1	−1	0.35	0.35	−0.35		0.35	0.35	−0.35	
								α_{21}	1	1	0.3	0.7667
Alternative 2 vs. Alternative 3 $sgn(e_{ij} - e^*_{ij})$												
Criterion 1	$e_{21} - e_{31}$	1	1	1	0.65	0.65	0.65		0.65	0.65	0.65	
Criterion 2	$e_{22} - e_{32}$	−1	−1	−1	−0.35	−0.35	−0.35		−0.35	−0.35	−0.35	
								α_{23}	0.3	0.3	0.3	0.3
Alternative 3 vs. Alternative 1 $sgn(e_{ij} - e^*_{ij})$												
Criterion 1	$e_{31} - e_{11}$	−1	−1	−1	−0.65	−0.65	−0.65		−0.65	−0.65	−0.65	
Criterion 2	$e_{32} - e_{12}$	1	1	1	0.35	0.35	0.35		0.35	0.35	0.35	
								α_{31}	−0.3	−0.3	−0.3	−0.3
Alternative 3 vs. Alternative 2 $sgn(e_{ij} - e^*_{ij})$												
Criterion 1	$e_{31} - e_{21}$	−1	−1	−1	−0.65	−0.65	−0.65		−0.65	−0.65	−0.65	
Criterion 2	$e_{32} - e_{22}$	1	1	1	0.35	0.35	0.35		0.35	0.35	0.35	
								α_{32}	−0.3	−0.3	−0.3	−0.3

Table 7
Quantitative dominance score.

			c=1	$a_{ii'}$
Alternative 1 vs. Alternative 2 $(e_{ij} - e^*_{ij})$				
Criterion 3	$e_{13} - e_{23}$	0.2	0.05	0.05
Criterion 4	$e_{14} - e_{24}$	0.15	0.1125	0.1125
			a_{12}	0.1625
Alternative 1 vs. Alternative 3 $(e_{ij} - e^*_{ij})$				
Criterion 3	$e_{13} - e_{33}$	0.45	0.1125	0.1125
Criterion 4	$e_{14} - e_{34}$	−0.1	−0.075	−0.075
			a_{13}	0.0375
Alternative 2 vs. Alternative 1 $(e_{ij} - e^*_{ij})$				
Criterion 3	$e_{23} - e_{13}$	−0.2	−0.05	−0.05
Criterion 4	$e_{24} - e_{14}$	−0.15	−0.1125	−0.1125
			a_{21}	−0.1625
Alternative 2 vs. Alternative 3 $(e_{ij} - e^*_{ij})$				
Criterion 3	$e_{23} - e_{33}$	0.25	0.0625	0.0625
Criterion 4	$e_{24} - e_{34}$	−0.25	−0.1875	−0.1875
			a_{23}	−0.125
Alternative 3 vs. Alternative 1 $(e_{ij} - e^*_{ij})$				
Criterion 3	$e_{33} - e_{13}$	−0.45	−0.1125	−0.1125
Criterion 4	$e_{34} - e_{14}$	0.1	0.075	0.075
			a_{31}	−0.0375
Alternative 3 vs. Alternative 2 $(e_{ij} - e^*_{ij})$				
Criterion 3	$e_{33} - e_{23}$	−0.25	−0.0625	−0.0625
Criterion 4	$e_{34} - e_{24}$	0.25	0.1875	0.1875
			a_{32}	0.125

Table 8
Standardization for qualitative dominance score.

$\delta_{ii'}$	$(\alpha_{ii'} - \alpha^-)/(\alpha^+ - \alpha^-)$	
δ_{12}	$(\alpha_{12}$-min$(\alpha_{ii'}))/($max$(\alpha_{ii'})$-min$(\alpha_{ii'}))$	0
δ_{13}	$(\alpha_{13}$-min$(\alpha_{ii'}))/($max$(\alpha_{ii'})$-min$(\alpha_{ii'}))$	0.6957
δ_{21}	$(\alpha_{21}$-min$(\alpha_{ii'}))/($max$(\alpha_{ii'})$-min$(\alpha_{ii'}))$	1
δ_{23}	$(\alpha_{23}$-min$(\alpha_{ii'}))/($max$(\alpha_{ii'})$-min$(\alpha_{ii'}))$	0.6957
δ_{31}	$(\alpha_{31}$-min$(\alpha_{ii'}))/($max$(\alpha_{ii'})$-min$(\alpha_{ii'}))$	0.3043
δ_{32}	$(\alpha_{32}$-min$(\alpha_{ii'}))/($max$(\alpha_{ii'})$-min$(\alpha_{ii'}))$	0.3043

Table 9
Standardization for quantitative dominance score.

$d_{ii'}$	$(a_{ii'} - a^-)/(a^+ - a^-)$	
d_{12}	$(a_{12}$-min$(a_{ii'}))/($max$(a_{ii'})$-min$(a_{ii'}))$	1
d_{13}	$(a_{13}$-min$(a_{ii'}))/($max$(a_{ii'})$-min$(a_{ii'}))$	0.61538
d_{21}	$(a_{21}$-min$(a_{ii'}))/($max$(a_{ii'})$-min$(a_{ii'}))$	0
d_{23}	$(a_{23}$-min$(a_{ii'}))/($max$(a_{ii'})$-min$(a_{ii'}))$	0.11538
d_{31}	$(a_{31}$-min$(a_{ii'}))/($max$(a_{ii'})$-min$(a_{ii'}))$	0.38462
d_{32}	$(a_{32}$-min$(a_{ii'}))/($max$(a_{ii'})$-min$(a_{ii'}))$	0.88462

Table 10
Overall dominance measure.

$D_{ii'}$	Qualitative O $\delta_{ii'} \times 0.60$	Quantitative C $d_{ii'} \times 0.40$	$\sum$
D_{12}	0	0.4	0.4
D_{13}	0.41739	0.246153846	0.66355
D_{21}	0.6	0	0.6
D_{23}	0.41739	0.046153846	0.46355
D_{31}	0.18261	0.153846154	0.33645
D_{32}	0.18261	0.353846154	0.53645

Table 11
Resulting appraisal score.

	$\sum_{i'} \frac{Di'i}{Dii'}$	s_i	$1/s_i$	Rank
s_1	$(D_{21}/D_{12})+(D_{31}/D_{13})$	2.0070565	0.498242089	2
s_2	$(D_{12}/D_{21})+(D_{32}/D_{23})$	1.8239538	0.548259494	1
s_3	$(D_{13}/D_{31})+(D_{23}/D_{32})$	2.8362568	0.352577386	3

6. Results and analysis

6.1. Ship selection based on fuzzy EVAMIX

The result of gas carrier selection by using the fuzzy EVAMIX method is reported in Table 11. Based on the opinions of six experienced experts, the rank is obtained as Alternative 1 (LPG) the 2nd; Alternative 2 (LNG) the 1st; and Alternative 3 (LEC) the 3rd. Alternative 2 (LNG) is selected as the most preferred ship among three.

The following facts can explain the reason why LNG is most preferred. The outlook for the LNG sector generally appears optimistic in the long-term, with increasing global demand for clean energy expected to provide supply to natural gas consumption. The uptake of LNG as a marine fuel is also expected to increase further, as the shipping industry moves further towards reducing carbon emission. As a result, LNG carriers are benefited by the IMO (International Maritime Organisation) regulation on sulphur emission with effective on 1 January 2020. Therefore, the LNG carrier sector is on course for positive years ahead. Ship values of LNG carriers remain relatively healthy and are increasing gradually. Compared to LPG and LNG, the ethylene (i.e. Alternative 3) sector is relatively stable.

Gas carriers are the most expensive type of tankers both to build and to operate. Tanker prices vary vs. the type, size, and age of the ship. In 2019, the 10-year-old Suezmax crude oil ship is approximately US$ 40 million; the 5-year-old product tanker, 50,000 DWT MR (medium-range), is about US$ 25 million; the 7-year-old chemical tanker price of 18,000 DWT is about $7 million; the 78,000 cbm LPG carrier, built-in 2001, was sold for US$ 24 million; the price of 174,000 cbm newly built LNG ship has been announced as US$ 186 million (Suloglu, 2019). Due to the high financial requirements, the number of companies that transport LPG and LNG in developing countries such as Turkey is quite low compared to the world scale. According to the website of e-marineeducation.com, the number of companies operating LPG and LNG carriers in Turkey is 7, and the number of LPG and LNG carriers is 19. In developing countries, gas transport is not operated by domestic maritime companies, but chemical transportation is more preferred. The gas transport sector is not a market known in Turkey.

These gas carriers are regarded as a ship type of very high risk. This is one of the biggest obstacles of such gas carriers to widespread in developing countries. Gas carriers also need the most highly trained personnel onboard and ashore. In addition to the technical knowledge of the personnel working on these gas carriers, their operation is demanded to be equipped with high safety awareness. Otherwise, accidents with severe consequences will likely occur.

Commercially LPG is preferred by shipowners, because the range of products it carries is wider than LNG carriers. Although LPG is identified with butane and propane, it has the same features as all gases specified in IMO Gas Code. These gases include other chemical gases, except LNG (methane) and frozen gases. To be more specific, a gas carrier designed for carrying LPG is allowed to carry not only LPG but also chemical gases as approved by the IMO Gas Code, subject to the extent allowed by ship particulars. For this reason, LPG may quickly create an explosive air-hydrocarbon mixture if exposed to atmospheric conditions. The physical properties of LPG (especially its specific weight, boiling point at the atmospheric pressure, critical temperature, and critical pressure amounts) vary considerably according to the content of the gas. These differences cause differentiation in the conditions of LPG transport (in terms of temperature and pressure) and in the design of transport and storage tanks. These situations also increase the construction costs of such ships considerably (Macit, 2008).

Table 12
Case combinations with different weights.

		Weights			Rank		
		s1	s2	s3	s1	s2	s3
Case 1	Current	0.49824209	0.54825949	0.35257739	2	1	3
Case 2	Qualitative criteria high	0.00010001	2.28456586	0.21878412	3	1	2
Case 3	Quantitative criteria high	1.59979826	9.9933E−05	0.57784656	1	3	2
Case 4	Qualitative high, C1 high	0.00010001	3919.10879	6.2669E−05	2	1	3
Case 5	Qualitative high, C2 high	6.1535E−05	1.1539E−05	13683.4764	2	3	1
Case 6	Qualitative high, C3 high	7.2227E−05	2.2854256	0.21873004	3	1	2
Case 7	Qualitative high, C4 high	8.0011E−05	2.28454576	0.21880638	3	1	2
Case 8	Quantitative high, C1 high	1.60000391	9.9933E−05	0.5777649	1	3	2
Case 9	Quantitative high, C2 high	1.59941348	6.6644E−05	0.57803331	1	3	2
Case 10	Quantitative high, C3 high	2.5991385	0.34660751	3.0432E−05	1	2	3
Case 11	Quantitative high, C4 high	0.38727688	6.9551E−05	2.33173799	2	3	1

6.2. Sensitivity analysis

Sensitivity analysis refers to discussing the change of results caused by the change of one criterion on other criteria so as to find out the sensitive criterion that have large influence on this fuzzy EVAMIX method. Sensitivity analysis is conducted in a manner similar to one of the decision making studies of Celik and Akyuz (2018). Case 1 is the current case discussed in Section 6.2. Case 2 and 3 are generated by setting the highest weights to all qualitative criteria and all quantitative criteria, respectively. Case 4 to 7 consider the highest weight to one qualitative criterion in turn. Case 8 to 9 allocate the highest weight to one quantitative criterion one by one.

The result of sensitivity analysis is given in Table 12 and partially validate the model. The observations of sensitivity analysis are as follows:

- The rank is more sensitive to quantitative criteria than qualitative criteria. It is due to the fact that the three alternative gas carriers are relatively similar in the quantitative criteria and thus the change of weights of quantitative criteria will amplify the small differences.
- Among the four attributes (C1 financial attribute, C2 technical attribute, C3 environmental attribute, and C4 operational attribute), the rank is least sensitive to C3 environmental attribute. This is because the relative weights of C1, C2, C3 and C4 are 0.39, 0.21, 0.10 and 0.30, respectively, and then the changes of C3 criterion weight has relatively small influence on the ranking.
- The swap to the ranking occurs when the quantitative criteria have a higher weight. Alternative 2 (LNG) is ranked 1st in many cases, which reveals that the degree of domination of Alternative 2 (LNG) and other two alternatives is partially independent of changes in the weights associated with the selected criteria.

The above results show that there is a coincidence that the ranking of gas carriers are consistent by using this fuzzy EVAMIX model. It can produce reasonable ranking and provide guidance to assist decision-making.

7. Conclusions

In this study, a decision support system is presented to assist in ship selection. Selecting which ship will provide the maximum benefit for ship investment is a significant problem. Multiple criteria might need to be taken into account when choosing a ship among multiple alternatives. These criteria include financial, technical, environmental, and operational factors. Although some of these criteria are expressed in numbers (objective weights, crisp values), some criteria can be unpredictable and immeasurable (positive expressions, fuzzy variables).

EVAMIX is a multi-criteria decision analysis (MCDA) method in which it compares the criteria and alternatives by using some binary relations in order to make final recommendations. In this study, EVAMIX as an outranking method is extended in three ways. First, a fuzzy extension is carried out because of its closeness to the human thought system. Second, the proposed approach enables multiple experts to participate in the group decision-making process. Third, we implement expert prioritization which assigns a coefficient based on the experts' professional experience, year, etc. A step-wise application shows the applicability of the proposed approach.

One of the limitations of this study is the number of decision-makers. In this study, six decision makers have been consulted. In the future, the expert group may be primarily expanded over different locations. Other limitation is the expert quality and experiences of the decision-makers in this work. Another limitation is that this study has applied a user-centred approach and invited experienced seafarers as experts in the process of expert prioritization. In order to reduce potential preference bias, future studies may collect various field experts' opinions and experts may include ship investors, shipowners, and other professions. The results of future studies may be compared with the results of this model in practical problems. As a result of the applications, the reliability and impacts of the decisions taken by the shipping companies will be observed.

Conflict of interest

The authors declare no conflict of interest.

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